Asset Information Decision-making Framework for the South African Navy

by

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Declaration

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Abstract

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Asset Information (AI) is essential for effective Asset Management (AM). Decision-makers rely on it for AM decision-making, where productive decision-making underpins success in AM. It became apparent that the effect of AI on the output of the mission-performing systems in the SA Navy (SAN) is not defined. Without defining the value of individual AI elements to organisational outputs it is difficult to determine which critical AI elements to acquire and maintain, and which are not beneficial. The purpose of this research is therefore to develop a framework to support decision making regarding AI elements in the SAN. The intention with this framework is to optimise AI in terms of cost effectiveness and support of higher order decision making requiring AI. Operational Availability (A_O) is a performance metric that is directly linked to the core outputs of the SAN and falls within the scope of AM. Therefore determining the effect of AI on the A_O of the SAN's systems is at the crux of this research.

This framework is developed from two sources in the research, theoretical knowledge and fieldwork. The literature study provides the theoretical base for the thesis as a whole and the Multi-Criteria Decision Making algorithm forms the structure of the framework. Research in the field, making use of experts in the SAN environment provides the content of the framework. Due to the complexity in firstly identifying critical AI elements and secondly determining their value to A_O, an exploratory mixed method design is used to collect data. After the first round of data collection a preliminary framework based on Analytical Hierarchy Process and Multi-Attribute Utility Theory (AHP-MAUT) principles are developed. The preliminary framework is used for the second round data collection. Data analysis is carried out using a combination of qualitative and quantitative methods. The final framework is presented in an Excel format (for ease of use) with automated processes that calculates the ranking of AI elements as well as statistical analysis which assists decision makers by offering some suggestions regarding the management of the AI elements.

The framework is validated through face validation and user assessment, both via questionnaires posed to an expert panel. According to the expert panel the framework is perceived as 1) useful 2) easy to use 3) practical 4) understandable and 5) flexible. Construct validity is also established, mainly via feedback from the face validation panel. The framework is a baseline version in an unexplored field in the SAN. As part of the conclusion of the thesis is noted that further refinements and validation in the field is required to verify the findings from this thesis.

Opsomming

Bate Inligting Besluitnemings raamwerk vir die Suid Afrikaanse Vloot

("Asset Information Decision-making Framework for the South African Navy")

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Bateinligting (BI) is noodsaaklik vir effektiewe batebestuur. Besluitnemers vertrou daarop vir batebestuur-besluitneming, waar produktiewe besluitneming sukses in batebestuur bekragtig. Dit het duidelik geword dat die effek van BI op die uitset van sisteme wat missies uitvoer in die SA Vloot (SAV) nie gedefinieër is nie. Sonder om die waarde van individuele BI-elemente ten opsigte van organisatoriese uitsette te definieër, is dit moeilik om te bepaal watter kritieke BI-elemente om te bekom en te onderhou, asook watter glad nie voordelig is nie. Die doel van hierdie navorsing is dus om 'n raamwerk te ontwikkel wat besluitneming rakende BI-elemente in die SAV sal ondersteun. Die doel van hierdie raamwerk is om BI te optimaliseer ten opsigte van koste-effektiwiteit en ter ondersteuning van hoër-orde besluitneming. Operasionele beskikbaarheid is 'n werkverrigting maatstaf wat direk verband hou met die kernuitsette van die SAV, en ook binne bestek van batebestuur val. Die bepaling van die effek van BI op die operasionele beskikbaarheid van SAV stelsels is dus die kern van hierdie navorsing.

Hierdie raamwerk word ontwikkel vanuit twee navorsing bronne, teoretiese kennis en veldwerk. Die literatuurstudie bied die teoretiese basis vir die tesis in geheel en die Multi-kriteria Besluitneming algoritme vorm die struktuur van die raamwerk. Die raamwerk se inhoud bestaan uit navorsing ingewin van kundiges in die SAV omgewing. Vanweë die ingewikkeldheid om eerstens kritiese BI-elemente te identifiseer en tweedens die waarde daarvan vir operasionele beskikbaarheid te bepaal, word 'n verkennede ontwerp vir gemengde metodes gebruik om data in te samel. Na die eerste rondte van data-insameling word 'n voorlopige raamwerk, gebaseer op die Analitiese Hiërargie Proses en Multi-kenmerk nutsteorie beginsels ontwikkel. Die voorlopige raamwerk word gebruik vir die tweede rondte van data-insameling. Data-analise word uitgevoer met behulp van 'n kombinasie van kwalitatiewe en kwantitatiewe metodes. Die finale raamwerk word aangebied in 'n Excel-formaat (vir gebruikersgemak) met outomatiese prosesse wat die rangorde van BI-elemente bereken, sowel as statistiese ontleding, wat besluitnemers help deur voorstelle te maak rakende die bestuur van die BI-elemente.

Die raamwerk word gevalideer deur middel van gesigsvalidering asook assessering deur gebruikers, beide deur middel van vraelyste wat aan 'n paneel kundiges voorgelê word. Volgens die paneel kundiges word die raamwerk beskou as 1) bruikbaar 2) maklik om te gebruik 3) prakties 4) verstaanbaar en 5) aanpasbaar. Konstruksiegeldigheid word ook vasgestel, hoofsaaklik deur terugvoering van die gesigvalideringspaneel. Die raamwerk is 'n basislyn weergawe in 'n onverkende veld in die SAV. As deel van die afsluiting van hierdie tesis word opgemerk dat verdere verfynings en validering in die veld nodig is om die bevindinge van die tesis ver verifieer.

Acknowledgements

I would like to express my sincere gratitude to the following people and organisations:

- My supervisor, Dr JL Jooste for his patience and guidance.
- The South African Department of Defence and the South African Navy for allowing data to be collected.
- The participants for completing the questionnaires and providing constructive feedback during the validation process.

To our Heavenly Father, through Him anything is truly possible.

Dedications

Hierdie tesis word opgedra aan my vrou, Marilize
- vir jou geduld, ondersteuning en liefde;
Aan my dogter, Lara - nou kan ons meer speel;
En laastens aan my ouers - die pad was lank, maar
ek het uiteindelik klaargemaak waar ek begin het.

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List of Acronyms

AHP	Analytic Hierarchy Process
AI	Asset Information
AM	Asset Management
ANP	Analytic Network Process
BSI	British Standards Institution
CAPEX	Capital Expenditure
CDM	Configuration and Data Management
CM	Cognitive Map
DEA	Data Envelopment Analysis
DOD	Department of Defence
DP	Development Plan
FSP	Force Structure Plan
EAM	Enterprise Asset Management
EC	Engineering Change
ELECTRE	Elimination Et Choix Traduisant la Realité (Elimination and Choice Expressing Reality)
FY	Financial Year
GM	Group Map
IAM	Institute for Asset Management
ILS	Integrated Logistic Support
ISO	International Organization for Standardization
ISS	Integrated Systems Sciences
IT	Information Technology

LCC	Life Cycle Cost
LE	Logistic Engineering
LSA	Logistic Support Analysis
LSAR	Logistic Support Analysis Records
MAUT	Multi-attribute Utility Theory
MCDM	Multi-criteria Decision-making
OHS	Occupational Health and Safety
OPDEF	Operational Defect
OSBL	Operational Support Base Line
OSIS	Operation Support Information System
PM	Product Management
PROMETHEE	Preference Ranking Organisation Method for Enriched Evaluation
PSM	Product System Manager
RAMS	Reliability Availability Maintainability and Supportability
ROC	Required Operating Capability
SADC	Southern African Development Community
SAN	South African Navy
SANAIDMF	South African Navy Asset Information Decision-making Framework
SANDF	South African National Defence Force
SE	System Engineering
SM	System Management
SWOT	Strengths Weaknesses Opportunities Threats
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution

Glossary

Asset
: "An asset is an item, thing or entity that has potential or actual value to an organization. The value will vary between different organisations and their stakeholders, and can be tangible or intangible, financial or non-financial" (ISO 55000, 2014)

Asset management
: "Coordinated activity of an organization to realise value from assets" (ISO 55000, 2014)

Asset management system
: "Management system for asset management whose function is to establish the asset management policy and asset management objectives" (ISO 55000, 2014)

Availability
: "Availability is a measure of the degree to which an item is in an operable state and can be committed at the start of a mission when the mission is called for at an unknown (random) point in time" (US Department of Defense, 2005)

Capability
: "A products capability is defined as its ability to perform a specified task in a given environmental or operational context" (S5000, 2016)

Data
: "Reinterpretable representation of information in a formalised manner suitable for communication, interpretation or processing" (ISO 8000–8, 2015)

Integrated logistics support
: "ILS is an integrated and iterative process for developing material and a support, maintenance strategy that optimizes functional support, leverages existing resources, and guides the system engineering process to quantify and achieve high performance with lower life cycle cost" (Podofillini *et al.*, 2015)

Information
"Knowledge concerning objects, such as facts, events, things, processes or ideas, including concepts, that within a certain context has a particular meaning" (ISO 8000–8, 2015)

Logistic support analysis
"A structured approach to increase in maintenance efficiency and reduction of the cost of providing support by preplanning all aspects of Integrated Logistics Support" (S3000, 2014)

Maintainability
"The term maintainability is used when the user wants to refer to how easy it is to return an item to its serviceable condition" (S5000, 2016)

Metadata
"Data that defines and describes other data" (ISO 8000–8, 2015)

Model based system engineering
"The formalized application of modelling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases" (BKCASE Editorial Board, 2014)

Operational availability
"The basic measure for real-world availability, as this term quantifies the degree to which an item is in an operable state at any time. Operational availability includes maintenance downtime caused by preventive or scheduled maintenance as well as logistic delay times" (US Department of Defense, 2005)

Product
"Any platform, system or equipment (air, sea, land vehicle, equipment or facility, civil or military)" (S3000, 2014)

Reliability (Also referred to as dependability)
"Reliability is the probability of an item to perform a required function under stated conditions for a specified period of time" (US Department of Defense, 2005)

System
"A combination of interacting elements organised to achieve one or more stated purpose" (Haskins, 2011)

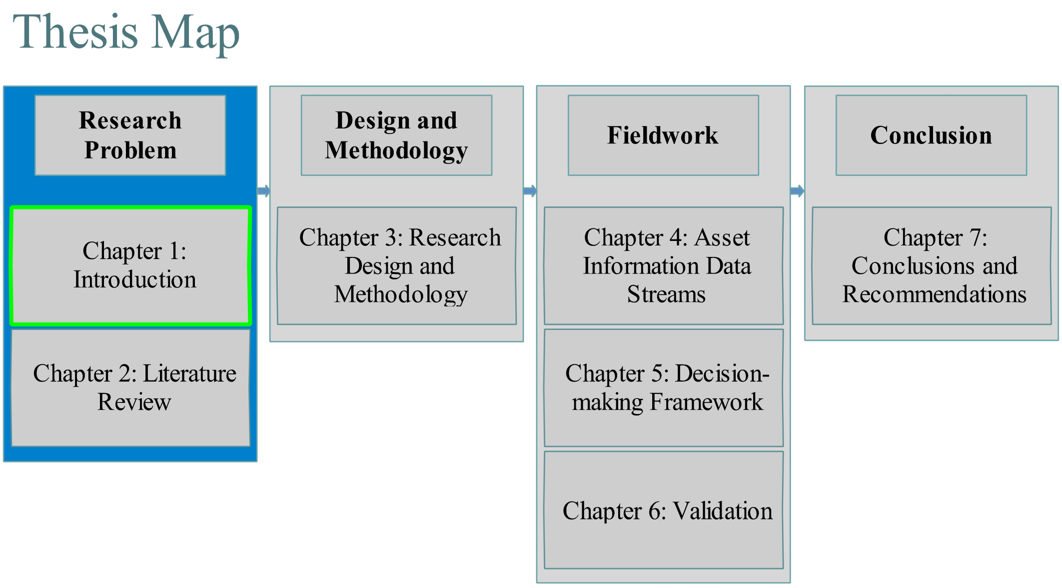
Systems engineering
"Systems engineering is an iterative process of top-down synthesis, development, and operation of a real–world system that satisfies, in a near optimal manner, the full range of requirements for the system" (Haskins, 2011)

Chapter 1

Introduction

"All models are wrong; some models are useful."

– *George E.P. Box (1919-2013)*



The aim of this chapter is to provide a brief theoretical background as well as contextualisation of the research, paving the way for the research problem statement, questions and objectives. The research design and methodology is then discussed briefly before stating the delimitations and limitations of the research. This chapter also provides a synopsis of the thesis.

1.1 Background and contextualisation

"Asset Management, including those aspects of Reliability and Maintenance related to it, offers an unexplored frontier for business to improve competitiveness" (Penrose, 2008). Organisations have the difficult task of maintaining operational effectiveness whilst reducing costs: capital, operating and support. Penrose (2008) also states that although capital expenditure (CAPEX) will increase with Asset Management (AM) implementation, a reduction of 24 – 30% is to be expected in maintenance costs, 30 – 40% in downtime and 70 – 75% in unplanned breakdowns.

The development and implementation of a successful asset management programme is however a process that requires a structured system. According to Penrose (2008) when 'Re-engineering' and 'Lean' were initially established, and the success stories spread, many company executives hastened to have those programmes implemented. Purposely formed consulting firms that claimed to be able to assist with implementation made incorrect recommendations due to a lack of a full understanding of how the business functions. The result was that critical systems and departments were under-resourced, which led to failures of the programme as a whole. Similar risks, of not applying resources to the correct areas, exist within AM.

The Institute of Asset Management (IAM) describes AM decision making as the element underpinning success in asset management, both in implementation and optimisation (IAM, 2015). To make the best decisions organisations must rely on asset information (AI) as shown in Figure 1.1. The requirements for AI are thus increasing as technology advances.

Armed forces are technologically driven – initially only the navies and air forces – but more recently armies as well (Gwendolyn and James, 2017). According to Gwendolyn and James (2017) military assets are large-scale systems where the technical domain plays a major role. South Africa's armed forces are no different. The definition of a system used in the South African National Defence Force (SANDF) (RSA Department of Defence, 2003) is: "a complete system is a combination of mutually dependent items, assemblies, facilities, testing and training equipment, personnel, material, data required or any equipment performing or supporting an operational role autonomously in its operational environment" (See Figure 1.2). This definition reveals the complexities involved in a typical military system. Although mutually dependent, the diverging nature of the components often clouds a clear line of sight as to the importance of certain critical components in meeting organisational objectives. The overarching objective of South Africa's Navy (SAN) according to Mapisa-Nqakula (2016) is: "to provide prepared and supported maritime defence capabilities for the defence and protection of South Africa". The core outputs and associated performance indicators are (Mapisa-Nqakula, 2016):

- Conducting ordered defence commitments in accordance with government policy and strategy, measured by the number of hours at sea per year; and
- Providing mission ready defence capabilities, measured by the percentage compliance with joint force employment requirements

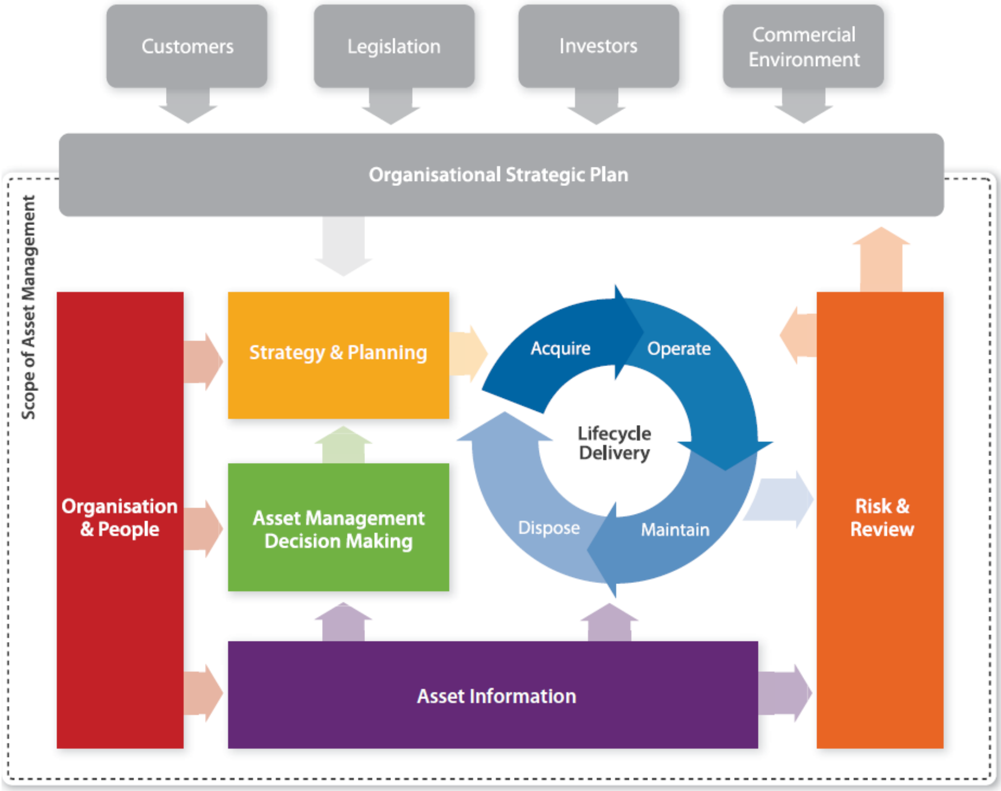


Figure 1.1: The IAM's conceptual AM model (IAM, 2015)

In order to conduct ordered defence commitments and provide mission ready defence capabilities naval systems must be able to "perform a specified task in a given environmental or operational context" and "be in a state to perform as required under given conditions at a given instance or over a given interval", which are the definitions for capability and availability, respectively (S5000, 2016; South African Navy, 2000). This correlates with the definition of system effectiveness according to Pennell and Knight (2005) which is: "a measure of the degree to which a system achieves a set of specific mission requirements. It is a function of availability, dependability, and capability".

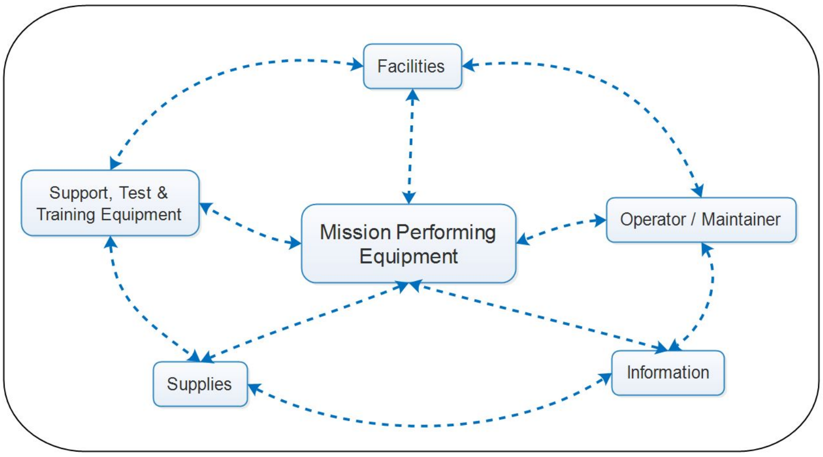


Figure 1.2: An autonomous system (Adopted from Sparrius (2017) and Pennell and Knight (2005))

Pryor (2008) argues that “operational availability is widely used as a readiness-related objective in the specification or requirements for military systems”.

The definition of availability and operational availability can be found in various military literature sources, which all more or less define it similarly. Availability being the “probability that a system will be able to perform its mission when required”(US Department of Defense, 2005). Availability is influenced by how often a system experiences downtime, and the time it takes to restore it to service. Both factors could be affected by inherent design characteristics or support system performance given a specific operating environment. Availability is measured in progressive stages, ‘inherent’ availability measuring availability in ideal conditions, with no downtime. ‘Achieved’ availability factors in downtime for preventive maintenance, but not any delays. ‘Operational’ availability takes into consideration everything expected in a real-world application including downtime for preventive and corrective maintenance as well as logistic and administrative delays (US Department of Defense, 1983). Operational availability is the appropriate measure according to US Department of Defense (2005) when considering the effects of both design and the support system.

Readiness levels and operational availability of military systems are used interchangeably by US Department of Defense (2005), where operational availability is further used as one of three performance measurement metrics providing an overall indication of field experience. The other two are mission success rates as well as operation and support costs. This provides insight into the versatility of operational availability as an attribute, as well as a parameter, of military systems.

Schuman and Brent (2005) are of the opinion that, time and again, AM is the last area looked at to maximise cost savings due to the fundamental complexity of the AM system's elements interaction and challenges in managing an asset in entirety over its life cycle. It is explained that management responsibility will often be transferred between departments or organisations when transitioning between life cycle stages. This results in disconnected objectives over the life cycle as each organisation or department operates within its own constraints and to its own objectives. The result is often actions that bring short-term relief (within one phase), but long-term damage (when viewed over the life cycle) due to incorrect decisions. For example, budget reductions to the wrong department or the shutting down or outsourcing of certain core operations. Unfortunately, circumstances may force an organisation to make difficult decisions, but how well informed the decision-makers are of the effects of their decisions is frequently not disclosed.

Making productive asset-related decisions requires organisations to equip their personnel with the correct information at the right time in the right format. In the operational deployment and maintenance phase of assets actual data can be collected about systems in their operating environments. According to Haskins (2011), during this phase, the systems engineering (SE) function analyses performance, monitors interfaces, conducts failure analysis, analyses logistics, and tracks and manages those which are essential to the ongoing support of the system. Various elements interact to enable the asset to fulfil its mission: one of these elements is AI which, in typical systems thinking, influences all other elements in the system and has its own elements. Collecting and managing information which is required for informed-decision making costs money. The ultimate achievement is to collect and maintain all data elements as described in the AM literature, but many organisations find it challenging and not cost-effective. Some areas will either not yield the same return as what was invested or have negligible effects, whilst areas that could potentially have advantageous results are neglected.

The ISO 55000 series of standards and its predecessor, PAS 55, are examples of standards that provide guidelines about what is required to derive value from assets. AM is defined as the: "coordinated activity of an organisation to realise value from assets" (ISO 55000, 2014). Once an AM system is established, ISO 55001 states that: "The organisation shall establish, implement, maintain and continually improve an asset management system, including the processes needed and their interactions" (ISO 55001, 2014).

ISO 55000 (2014) states that the operating context of an organisation is used to determine AM objectives, which in turn is integrated into an organisation by its leadership team. From here, coordinated plans and policies for managing assets are developed and operations executed accordingly (ISO

55000, 2014). Despite being a fundamental element that links all AM system elements, AI becomes predominant in the support of assets; the cornerstone upon which performance evaluation and improvements are based. The organisation must decide what must be evaluated as well as how it should be done in order to provide information about the management, performance and efficiency of assets in achieving organisational objectives (ISO 55001, 2014). Improvement opportunities should then be sought through inputs from performance evaluation, but be risk assessed before being implemented (ISO 55000, 2014).

The effect, whether positive or negative, of AI on the output of mission performing systems in the SAN is not defined. Not being able to identify critical AI elements could thus create risk in achieving outcomes. The risk assessment, or potential reward of improvement opportunities, is also uncertain as there is no framework that contains the essential features to understand the influence of AI within the SAN's AM system.

Various management systems work together to eventually produce the required outcome of an organisation (IAM, 2015). However, when researching the link between AI and organisational outputs, performance metrics that are linked to both the outputs as well as the AM system are required. The capability and availability of assets are measurable concepts that fall within the scope of AM and, as mentioned in the text above, are directly linked to the outputs of the SAN's mission-performing systems. The main focus of the research is to aid decision-making by defining the effect of AI on the operational availability[1] of the SAN's systems, which is complicated and not documented. With this knowledge, informed decisions can be made in adverse economic conditions regarding what information is critical to gather and maintain, also potentially effecting positive changes in business processes and rules, even management dashboards.

1.2 Problem statement and research questions

The problem is that there is no framework available to aid decision-making regarding asset information in the SAN.

[1]Capability not being part of the research is discussed as part of the boundaries of the study in section 1.5.

To address this problem and the associated unexplored field of research the primary research question that must be investigated is:

Can an asset information decision-making framework be constructed for the SAN?

In support of the primary research question the secondary research questions are:

1. *What critical decisions affecting operational availability of systems in the SAN are taken that required AI as input?*
2. *What are the AI data streams that support critical decision making affecting operational availability in the SAN?*
3. *How can a framework be constructed to understand the impact of each of the AI elements on operational availability?*

1.3 Research objectives

This section details the specific research objectives in order to respond to the above research questions. The primary objective of the research is to:

Develop an asset information decision-making framework for the SAN

To achieve the primary objective, a series of sub-objectives must be systematically achieved. These are as follows:

1. Establish the fundamentals in the relevant fields of study with a literature review:
   a) Review key concepts in AM and SE;
   b) Review the role of the SAN and contextualise its use of AM;
   c) Review strategic decision making.
2. Construct a well-grounded research methodology.
3. Identify critical AI based decisions taken in the SAN that have an influence on system operational availability.
4. Establish data streams required for decision-making.
5. Construct a preliminary framework.

6. Determine the influence of AI elements on the SAN's operational availability.

7. Consolidate the preliminary framework and the influence of AI on decisions into the South African Navy Asset Information Decision-making Framework (SANAIDMF).

8. Validate the SANAIDMF.

This study aims to achieve the above objectives in chronological order to ultimately answer the research question. The research design is summarised in the following section.

1.4 Research design and methodology overview

The research is based on a inductive approach making use of a mixed method exploratory sequential study. Creswell (2013) describes this method as starting an inquiry of qualitative data and analysis, then using the results in a quantitative phase. The top-down approach is followed to determine which AI elements are of importance to decision-making, after which each element's contribution to the operational outcomes of the SAN is quantified. Initially senior management officials from the technical environment of the SAN are asked exploratory questions in a survey-based questionnaire. In the first phase a link is established between AI and operational availability via decision-making. AI elements deemed important by experts for decision-making are also identified, which marks the end of the qualitative phase.

Based on the outcome of the first phase, a preliminary framework is constructed that contains the AI elements identified. The outcome of the qualitative phase is used to construct a questionnaire based on AHP-MAUT principles to collect and analyse data quantitatively for the determination of the relative importance of each AI element in achieving operational availability. The results of the two phases are used to construct a final framework which can be used for decision-making. The SANAIDMF is then validated by means of face validation and user assessment. These methods are used to ensure structural validity and to determine the accuracy of the findings.

1.5 Delimitations and limitations

The previous sections outlined the theoretical background, problem statement, research questions and methodology of this thesis. This section discusses the boundaries of the research.

The main boundaries of the study are:

1. The research is limited to AI of the SAN, which has a unique asset portfolio that is not profit driven. Although the research principles and decision-making framework can be applied in other industries, the initial data collected that leads to the SANAIDMF is collected specifically with the SAN's business processes and outputs in mind.

2. The study will not attempt to investigate the AI base for all decisions made in the SAN, but will focus only on decisions deemed critical by experts in the field. These decisions must have a significant influence on the operational availability of SAN mission performing equipment.

3. The research is furthermore limited to AI required for decision-making in the operational deployment and maintenance life cycle stage. The effects of what was implemented in the previous life cycle stages are observed in the operational deployment and maintenance stage, providing empirical evidence. Grounding the SANAIDMF in the operational deployment and maintenance life cycle stage reduces variables and creates more confidence in the validity of the framework. The SANAIDMF is, however, of interest to other life cycle stages and can be incorporated accordingly.

4. Capability, in terms of the system's inherent ability to perform a specified task, such as speed, endurance, detection range and surviving environmental conditions, will not be included in the study. The capabilities of military systems are established and driven from a strategic perspective by government policy, implemented in the planning and acquisition stages, and used in the operational deployment and maintenance phase. Capability thus falls outside the scope of this study.

5. According to the Oxford dictionary a framework is "a basic structure underlying a system, concept, or text". Jabareen (2009) defines a conceptual framework as a network of concepts that together provides a comprehensive understanding of a phenomenon, not an explanation. A theoretical framework should provide insight that makes sense in the real world. The purpose of the SANAIDMF is to uncover the connections between AI elements and asset performance. It is not intended to be a prescriptive model that describes statistical significance between variables, but rather a framework that provides an understanding of a phenomenon, which then aids the decision making process. The scope of this research does not permit the additional complexity and the timely collection of data that typically accompanies statistical models.

1.6 Thesis outline

The first three chapters cover the introduction and design of the research as well as the review of relevant literature. Chapter 4 details the first phase of data collection. Chapter 5 covers the second phase of data collection as well as the SANAIDMF. Chapter 6 is dedicated to validation before conclusions are made and recommendations are given in Chapter 7.

Chapter 1: Introduction

In Chapter 1 the research is introduced by proving background and context before stating the research problem. Research questions and research objectives follow, which leads to an overview of the research design and methodology. Delimitations and limitations of the study are given and a thesis outline concludes the chapter.

Chapter 2: Literature Study

Chapter 2 consists of a comprehensive review of literature relevant to the study. Three distinct domains are investigated: AM and SE, AM in the SAN as well as strategic decision-making.

Chapter 3: Research Design and Methodology

In Chapter 3 the research approach, design and methodology are detailed. The overall approach is discussed followed by the details of the design and reasoning of the methodology used.

Chapter 4: Asset Information Data Streams

In chapter 4, critical AI-based decisions taken in the SAN that have an influence on the operational availability of systems are identified by means of a qualitative survey. A survey-based questionnaire is administered to experts in the field and from the results data streams of AI elements are established.

Chapter 5: Decision-making Framework

In Chapter 5 a questionnaire based on AHP and MAUT principles is used to determine the influence of AI elements on the SAN's operational outcomes and systematically rank AI elements according to their relative utilities.

Chapter 6: Validation

Chapter 6 details the validation of the SANAIDMF. Success factors are identified and used in face validation and user assessments.

Chapter 7: Conclusions and Recommendations

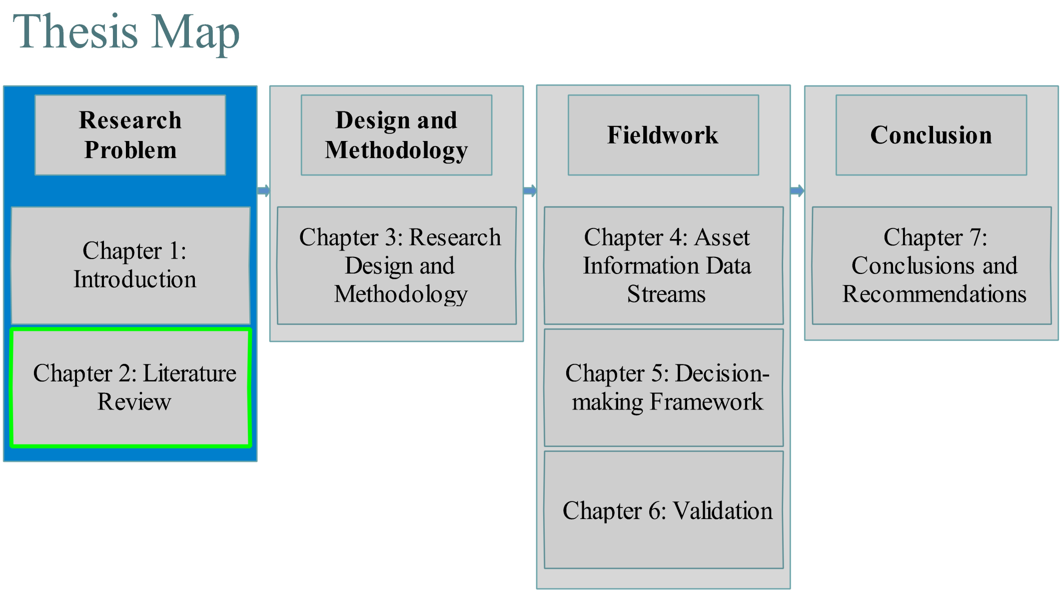
In Chapter 7 the results are deliberated and conclusions drawn. Recommendations for future research and the contribution to industry are discussed.

1.7 Chapter conclusion

Chapter 1 introduces the research starting with a background and contextualisation section followed by the research problem statement and questions. The primary and secondary research objectives are stated and an overview of the research design given. The delimitations and limitations of the study are discussed and the chapter concludes with an outline of the thesis. As per the thesis outline the next chapter provides a review of relevant literature.

Chapter 2

Literature review



Chapter 2 serves as the theoretical foundation for the chapters that follow by reviewing literature in support of the research problem and objectives. Relevant asset management (AM) literature is reviewed to contextualise the research problem. Thereafter, the SAN literature is reviewed with specific focus on AM and AI in the SAN. The SAN management system is based on system engineering principles and therefore system engineering, to the extent as it is applicable to this thesis, is reviewed after the SAN section. The fourth, and final part of this chapter is a review of decision-making theory, as it forms a integral part of the methodology of this research.

2.1 Asset management

Asset Management (AM) is central to this thesis, therefore the intended purpose of this section is to provide a comprehensive review of AM. This is achieved by exploring the following concepts and philosophies of AM: origins and definition; an overview; fundamentals; the AM system and its elements, as well as asset information and asset information systems.

2.1.1 AM origins and definitions

Serviceable machinery (physical assets) has been a requirement for successful business operations since the start of the industrial era; however, the focus was initially only on the operational phase of the asset's life cycle. Before World War II downtime of physical assets was not critical and as such a "fix it when it broke" philosophy was adopted (Moubray, 1992). During World War II the war time pressure changed the landscape and preventive maintenance policies were adopted with increased demand for good quality products (Moubray, 1992). From there, progression was again made in the 1960s – 1980s extending to operations research, reliability, condition monitoring, computerisation and eventually life cycle management (Barry, 2011; Moubray, 1992). It was during the 1980s that multi disciplined teams and the term AM started being used in three distinct parts of the world (IAM, 2015):

1) The European North Sea oil and gas industry as a consequence of the Piper Alpha oil disaster (UK).

2) The public sector in New Zealand and Australia required intervention with regards to its service delivery and costs.

3) Federal Asset Management policies for America's public works.

Subsequently during the 1990s AM became a field that required an interdisciplinary strategy to ensure that the optimum mix of skills is used to protect private and public capital expenditure (CAPEX) (Amadi-Echendu *et al.*, 2010b).

AM has, over the years, been a phrase claimed by many an industry, resulting in an ambiguous term (Hastings, 2010; IAM, 2015). Woodhouse (2006) states that the financial services industry uses AM to describe managing of an investment portfolio with the aim of maximising returns, whilst directors and analysts are under the impression that AM centres around corporate acquisitions, mergers, return on investment and "asset stripping". Maintenance specialists have re-branded their field into AM to gain more credibility, because to a board of directors and financial managers AM sounds worthy of a bigger budget than maintenance (Woodhouse, 2011; Moore, 2014).

Following on the 'shift from maintenance to AM', software traders saw an opportunity and started describing "Asset Information Management Systems" as "Enterprise Asset Management Systems" (Woodhouse, 2011). Woodhouse (2011) continues by saying that this created the fallacy that AM is technology driven, leading to unnecessary capital expenditure for an IT system that the organisation must conform to, not the other way around. He furthermore states that when diving into the information system environment, AM is interpreted as tracking the location and status of equipment, i.e. 'asset tracking' making use of bar-coding or tagging (Woodhouse, 2011).

The above applications and interpretations of AM are examples of selectively applying elements of AM without taking advantage of the synergy which emerges elements work together to realise value from assets. According to Woodhouse (2006) only a small number of asset owners and operators chose to accept AM as a whole in the custody and usage of fixed assets.

In 2004 the first AM standard was published to fill an industry void – Publicly Available Specification (PAS) 55. PAS 55 was updated in 2008 and eventually superseded by the ISO 55000 series of standards in 2014. These standards were written primarily for the managing of physical assets; part 1 of PAS 55 is appropriately titled: "Specification for the optimised management of physical assets" PAS 55-1 (2008). ISO 55000 is in contrast written for other asset types also and deliberately only uses the word asset, not physical asset (Moore, 2014). It does however state that the ISO standard is: "intended to be used for the managing of physical assets in particular, but can also be applied to other asset types" (ISO 55000, 2014). Hastings (2010) does indeed list five different asset types in an organisation: Financial, Physical, Human, Information and Intangible. However, PAS 55-1 (2008) explains that the presence of other asset types in a physical asset orientated specification is required as AM is intertwined with other categories of assets in the systems structure of a business. According to ISO 55000 (2014) an organisation's asset types are affected by amongst other the "nature and purpose" and the stakeholder's expectancies and requirements.

Moore (2014) is of the opinion that in most AM strategies too much attention is paid to day-to-day management and maintenance activities and not enough to: "delivering value through effective asset utilisation". IAM (2015) concurs by saying that AM is less about what is done to assets, but more about extricating value from them. However, maximising the value achieved across the life cycle of an asset requires optimised decision-making (IAM, 2015; Woodhouse, 2006). This in turn requires meticulous and tailored asset information[1], supporting those decision-making activities (IAM, 2015; ISO 55000,

[1] Asset information is at the core of this thesis and is discussed in detail in Section 2.1.4.4.

2014).

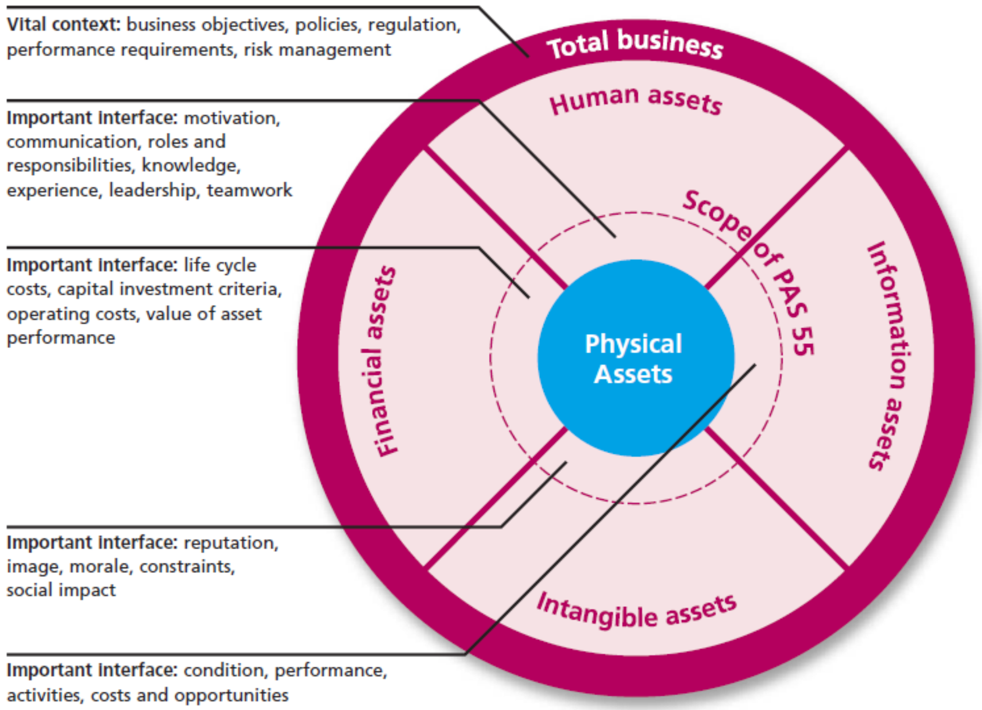


Figure 2.1: Interfaces of physical assets and other asset types according to PAS 55-1 (2008)

To set the scene for this thesis the interpretation of 'asset', 'AM' and 'PAM' must be discussed. Davis (2015) states that the definition of an asset is: "Any item of economic value owned by an individual or a corporation". The definition of an asset according to PAS 55-1 (2008) for the application of the standard is: "plant, machinery, property, buildings, vehicles and other items that have a distinct value to the organisation". This definition is very much orientated towards only physical assets. However, as mentioned before, PAS 55-1 (2008) acknowledges that asset types are interlinked and although not specifically covered by the standard, interfaces must be managed for business success (see figure 2.1). The latest literature has an evolved definition of an asset (ISO 55000, 2014; IAM, 2015; GFMAM, 2014):

> "item, thing or entity that has potential or actual value to an organisation".

Value can be "tangible or intangible, financial or non-financial, and includes considerations of risks and liabilities" (ISO 55000, 2014), ie inclusive of all asset types. Stander (2015) researched the possibility of a financial valuation method specifically aimed at big data and information. During that qualitative study, where a literature review and interviews were used, a decision-based valuation method was developed as a proof of concept. Interestingly, this method makes use of a top-down approach, first establishing which decisions require information and data collection before attempting to valuate data and information. This type of approach swiftly identifies information or data of little to no value. Only data fed into decision nodes are analysed, taking into account the effect of shared data streams, to assign a financial value. The decision-based valuation method is a generic valuation method built on the accounting perspectives of profits and return on investment. It does not provide for the valuation of AI in terms of achieving operational outcomes as required by AM of the defence industry.

AM is defined by ISO 55000 (2014) as:

> "coordinated activity of an organisation to realise value from assets"

A more descriptive definition of AM is given by Hastings (2010) as: "Asset Management is the set of activities associated with: identifying what assets are needed, identifying funding requirements, acquiring assets, providing logistic and maintenance support systems for assets and disposing of assets so as to effectively and efficiently meet the desired objective". The assorted definitions of AM express more or less the same thing according to Hastings (2010) i.e. the integrated use of technical, financial, risk, safety, design and management professionals at the appropriate life cycle stage to achieve objectives (IAM, 2015; Hastings, 2010). It must be noted that the terms AM and PAM are often interchanged in literature; however, these terms will be combined and referred to as AM from here on in this thesis.

2.1.2 AM overview

The AM landscape is partially captured in the ISO 55000 series of standards in that it contains the AM fundamentals, which forms the core of the AM landscape. What ISO 55000 does not contain is the 39 AM subjects, which together with the AM fundamentals describe the scope of AM (IAM, 2015; Berenyi, 2014; GFMAM, 2014). According to ISO 55000 (2014) the fundamentals on which AM are based are: value; alignment; leadership and assurance. The 39 AM subjects are shown in Figure 2.2. Due to their importance in the context of this thesis the ISO 55000 series of standards as well as the 39 AM subjects will be discussed in detail in Sections 2.1.3 and 2.1.4.

It is, however, crucial to highlight the role of the AM fundamentals and subjects, IAM (2014) explains:

> *"The 39 Subjects describe the body of Asset Management knowledge as a whole, whereas ISO 55001 (and PAS 55) specify the requirements for an organisation's management system – to direct, control and continually refine Asset Management."*

The IAM (2014) continues by saying that comprehension of the management component i.e. ISO 55000 series of standards alone cannot be regarded as proficiency in the whole of AM. The subjects are intended to support the management standard and explain AM activities from the perspective of how asset management could be implemented, whereas the management standard identifies what should be in place IAM (2015).

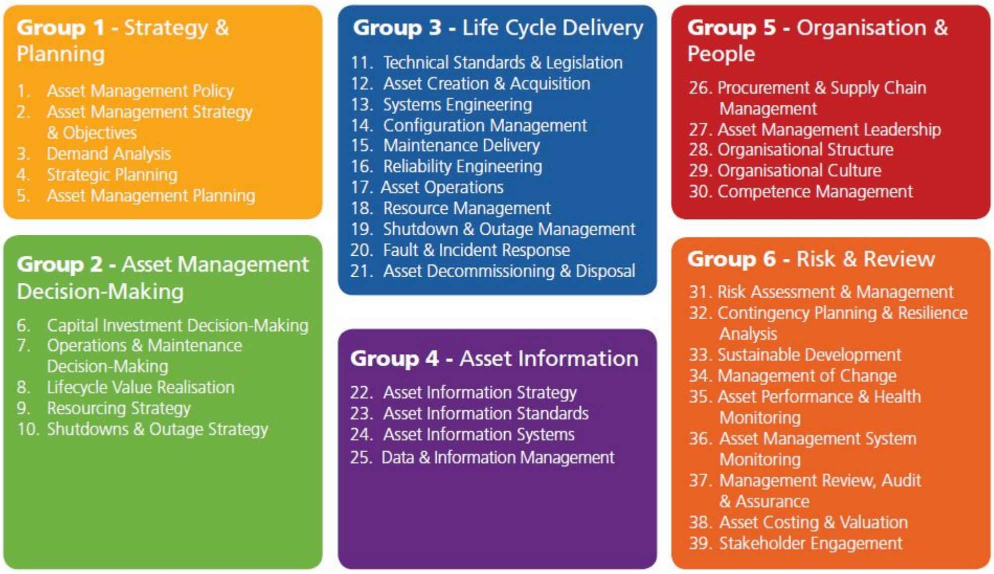


Figure 2.2: Asset management subject groups and 39 AM landscape subjects (Adapted from IAM (2015)).

Hastings (2010) describes the scope of AM by stating: "it is needed to provide asset knowledge and the capacity for related management and decision support activities within the context of our business". He continues by saying that in terms of planning and budgeting AM is relevant in both Capital Expenditure (CAPEX) and Operating Expenditure (OPEX) to ensure asset capability, continuity, logistic support, procurement, maintenance and regulatory compliance (Hastings, 2010).

The IAM (2015) is of the opinion that there is no unique model to delineate AM, but rather that an organisation should adopt and modify a model to be suitable based on needs. As a reference point the IAM created a conceptual model of AM. This model is shown in Figure 1.1, but repeated in Figure 2.3 for

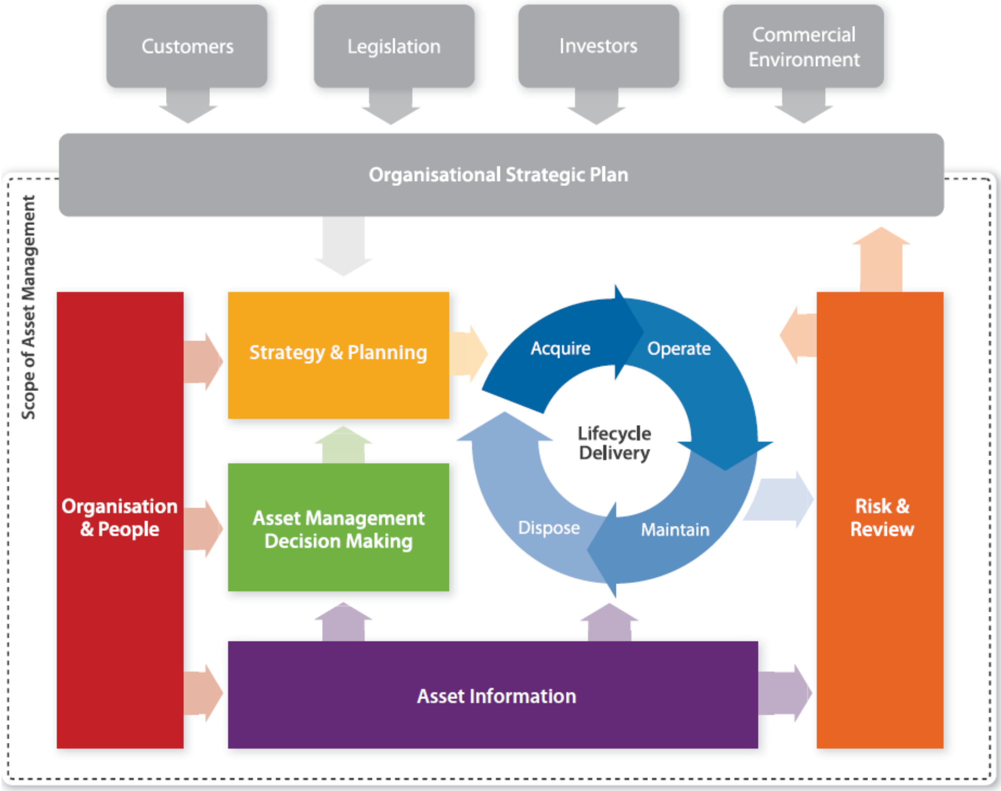


Figure 2.3: The IAM's conceptual AM model – repeated (IAM, 2015)

ease of reading. This representation consists of the six AM subject groups that align with those of the 39 AM subjects as shown in Figure 2.2. The conceptual model is intended to give a high-level description of the scope of AM, but also draws attention to the fact the AM is about integration of various facets of business, not acting in isolation (IAM, 2014). The representation furthermore reflects that AM is an integrative network that enables an organisation to strategise, plan and execute activities in alignment with organisational goals. The critical role of asset information as a fundamental element and pivot point for realising value is also shown.

ISO 55000 (2014) states that AM involves "balancing of costs, risks, opportunities and performance" in realising value. In contrast Woodhouse (2011) argues that balancing, in terms of mere equality of impact and achievement, is not what is desired of AM. In search of value, conflicting elements must be combined in a manner that most suits the organisation, often a trade-off between two conflicting elements: risk and cost (Woodhouse, 2011). Optimisation, rather than balancing, is more accurate when establishing the best value compromise regarding critical decisions (Woodhouse, 2011; IAM, 2015). Criticality is defined by IAM (2015) as: "a measure of the importance of an asset to the delivery of an organisation's objectives". It follows that a critical asset is an: "asset having the potential to significantly impact on the achievement of the organisation's objectives" (ISO 55000, 2014). The level of criticality is proportionate of the level to which business outcomes are reliant on an asset's operation (IAM, 2015). Understanding of criticality is key to prioritising and ultimately managing risk (IAM, 2015). Criticality is not only applicable to assets, but also asset systems, that can be categorised as performance-critical, safety-critical or environmental-critical (ISO 55000, 2014).

2.1.3 AM fundamentals

ISO 55000 (2014) states that AM is rooted in 4 fundamentals, that must be threaded into the fabric of any AM endeavour to realise success from it. The fundamentals are:

Value There must be an understanding that assets (of any type) exist to produce value (tangible or intangible) to an organisation and those with vested interests. AM therefore does not concentrate solely on the asset, but must be concerned with delivering value by using the asset effectively over its life-cycle (ISO 55000, 2014; GFMAM, 2014; Moore, 2014).

Alignment "Asset management translates the organisational objectives into technical and financial decisions, plans and activities" (ISO 55000, 2014; GFMAM, 2014). IAM (2015) states that this requires making the ultimate aim visible to staff physically executing tasks (bottom-up) and day-to-day activities being carried out visible to executives making decisions (top-down).

Leadership Leadership, and instilling a culture of dedication towards AM, is critical in accomplishing a fully operational AM system (ISO 55000, 2014). This must be practised on all leadership levels (IAM, 2015).

Assurance Along with AM comes assurances that expectations will be met ISO 55000 (2014). The AM assurance architecture comprises of "policies, plans, business processes and information systems to give assurance that asset management activities will be delivered, along with competent resources to monitor and demonstrate assurance to the appropriate levels of management" (IAM, 2015).

Although IAM (2015) agrees with the number and detail of the fundamentals it adds that there are additional features that distinguish AM from other management disciplines:

Whole life cycle focus Many variations for the naming and number of life cycle stages exist, but the common principle is that the stages should include all management activities from the initial notion to disposal (IAM, 2015). The feature that differentiates AM is thus the integration of activities over the entire life cycle. “Integration particularly affects the design phase, which can determine as much as 80% of the total life cycle costs of an asset” (IAM, 2015). Asset life cycle stages and variations are shown in Figure 2.4.

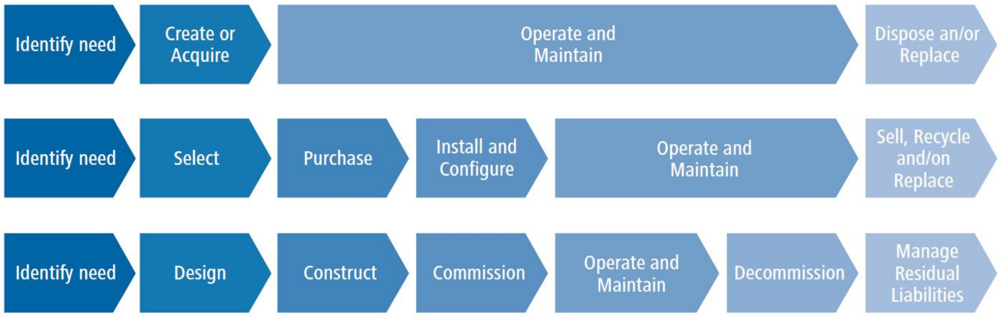


Figure 2.4: Asset life cycle stages and examples of variations (Adopted from IAM (2015)).

AM decision making IAM (2015) states that “competent, consistent, optimal decision-making” is crucial to asset management. Optimisation must always be borne in mind when dealing with the decision as well as the decision-making process. “Simple, non-crucial decisions can, and should, be made with (educated) common sense, whereas higher impact decisions, with multiple influences, options, timings or interdependencies require systematic, multi-disciplined *[sic]* and auditable decision-making processes” (IAM, 2015). Decision-making is at the centre of the research and will thus be reviewed in detail in section 2.4.

2.1.4 ISO 55000 series of standards and the 39 AM subjects

The Global Forum on Maintenance and Asset Management (GFMAM, 2014) indicates that the AM landscape comprises of three areas, namely: the core; knowledge and practices areas; and the supporting area. The supporting area is a body of knowledge, consisting of standards and practices that do not form part of AM, but influence AM decisions (GFMAM, 2014). Examples include, but are not limited to: finance standards, engineering standards, engineering competences and quality standards. GFMAM (2014) explains that the knowledge and practice areas are determined by the knowledge of AM practitioners, within their individual scope of practice.

The core of the AM landscape consists of AM fundamentals and AM subjects, where the AM subjects are collated into six groups. However, GFMAM

(2014) stresses that the allocation of the subjects: "is an arbitrary division of the discipline into individual subjects for the purpose of understanding the breadth and components of asset management more clearly. They cannot be treated as self-standing and independent and it is not possible to understand asset management properly without addressing them all as a holistic integrated body of knowledge". Although a holistic approach is advocated, it is beyond the scope of this thesis to incorporate all of the AM subjects in detail in the research. The research objective is aimed at AI; however, the interactions with other subjects or groups cannot be discounted. Therefore, a brief summary of the pertinent facts of each group follows, with an in-depth review of the decision-making and AI groups

2.1.4.1 Strategy and planning

This group's subjects are meant to ensure that AM activities are consistent with organisational objectives, constraints and stakeholder requirements (IAM, 2015; GFMAM, 2014). This provides traceability from day-to-day activities to organisational objectives, providing employees with a direct line of sight regarding their impact in the organisation (IAM, 2015).

The activities of this group governs the development, implementation and improvement over time of AM within the organisation (IAM, 2014). It needs to consider the demand on assets, as well as the required output (current and projected) and the various options for realising the objectives at the minimum life cycle cost (IAM, 2014). The majority of strategic activities are concerned with the long term requirements of the asset. The AM strategy, together with integrated AM decision-making activities, then provides the guidelines that enable investment strategies (IAM, 2014). In addition to asset requirements, it is also necessary to concentrate on parallel development of the AM system that supports the assets (IAM, 2014). Improvements must be coordinated with other enabling elements such as AI. AI must be developed to support cost and risk analysis of current and future performance and capabilities of assets (IAM, 2014; GFMAM, 2014).

The strategy and planning group consists of the following subjects (IAM, 2015):

1. AM policy;
2. AM strategy and objectives;
3. Demand analysis;
4. Strategic planning;
5. AM planning.

2.1.4.2 Asset management decision-making

Knowledge applied within the appropriate decision-making framework is at the crux of making good AM decisions (IAM, 2014). In order to maximise the realisation of value from assets, it is crucial for any organisation to have effective AM decision-making in place (IAM, 2015). The framework should be set in the 'Strategy and Planning' group, which would then guide the AM decision-making process (IAM, 2014). Asset knowledge is essential when making decisions and, according to IAM (2014), asset knowledge can be grouped into three areas:

Strengths and Weaknesses: Discern the criticality of assets, as well as their condition

Opportunities: Any steps that can be put in place to improve the condition of current assets, or any new technologies that can be implemented to improve overall AM output

Threats: Risks of not producing the required output and identifying actions to mitigate these risks

Similarly Woodhouse (2005) groups the decision support aid into two categories:

Provide greater clarity about the nature of the problem or opportunity: This entails any number of data collection, condition monitoring, reporting, pattern finding, root cause analysis or inspection techniques. The idea is to first define what is seen as a problem, then detect and then diagnose problems. With the abundance of data available care must be taken to target discovery and ensure that the correct information is extracted without being overloaded by the data

Evaluate solutions: Numerous solutions are available to evaluate the cost-risk impact of any solution. However, a good practice is to let the complexity of the solution be governed by the criticality of the decision; more complexity requires more care and rigour.

AM decision-making is spread over the complete life cycle of an asset, including planning, acquisition, operation and maintenance, and disposal, (IAM, 2015). The systems approach is used in order to take cognisance of the restrictions imposed on each life cycle stage due to changing requirements and to determine if the life cycle solution will deliver the value as expected by the stakeholders (IAM, 2015). Woodhouse (2005) is of the opinion that doing the right things (being effective) is more important than being efficient (doing the chosen tasks right). Deciding where and when to take action is key.

The AM decision-making group consists of the following subjects (IAM, 2015):

1. Capital investments decision-making;
2. Operations and maintenance decision-making;
3. Life cycle value realisation;
4. Resourcing strategy;
5. Shutdowns and outage strategy.

2.1.4.3 Life cycle delivery

The subjects in this group implements the AM plans that were developed in the Strategy and Planning group (IAM, 2015). Part of this group is involved in "an interdisciplinary, collaborative approach to derive, evolve and verify a life cycle balanced system solution which satisfies customer expectations and meets public acceptability" (GFMAM, 2014). Reliability engineering is also part of this group which controls activities to ensure that assets operate "to a defined standard for a defined period of time in a defined environment"(GFMAM, 2014). This includes developing the plans and processes to support Reliability-Availability-Maintainability-Supportability (RAMS) Modelling.

Good AM practices in controlling activities and associated risks over the life cycle of the assets are essential if opportunities are to be identified (IAM, 2015). IAM (2014) states that it is in AM life cycle delivery activities where the greatest portion of expenditure is experienced. Consequently, the life cycle should not be seen as a once through process – in order to continuously improve it is imperative that improvement opportunities identified in the operations and maintenance phase are fed back to future asset creation and acquisition phases via systems engineering activities (IAM, 2014). Some of the improvement opportunities identified during the operations and maintenance life cycle stage are based on data and information from faults and incidents experienced in this phase (GFMAM, 2014). In addition, documented information is required to show that the processes meant to deliver business objectives are performing as intended.

The life cycle delivery group consists of the following subjects (IAM, 2015):

1. Technical standards and legislation;
2. Asset creation and acquisition;
3. Systems engineering;

4. Configuration management;
5. Maintenance delivery;
6. Reliability engineering;
7. Asset operations;
8. Resource management;
9. Shutdown and outage management;
10. Fault and incident response;
11. Asset decommissioning and disposal.

2.1.4.4 Asset information

ISO 8000–8 (2015) defines information as: "knowledge concerning objects, such as facts, events, things, processes or ideas, including concepts that within a certain context have a particular meaning", whereas data is defined as: "re-interpretable representation of information in a formalised manner suitable for communication, interpretation or processing". IAM (2014) states that knowledge is the basis for decision-making and that the following subjects make up the asset knowledge enablers group:

1. Asset information strategy;
2. Asset information standards;
3. Asset information system;
4. Data and information management.

These four subjects have a synergistic relationship where data and information can generally be improved by the management approach set out in the AI strategy. The AI strategy prescribes how organisations obtain, store, use, evaluate and improve AI to sustain the AI quality levels required to support assets (IAM, 2015). The strategy must also define how AI and data will be managed after being used for their intended purpose: when to archive or destroy. The two main considerations in establishing the strategy are the effects on life cycle costs (LCC) and the value added to the organisation by the AI (IAM, 2015).

The AI standards and guidelines set by the organisation are based on the needs defined by the AI strategy GFMAM (2014). These typically defines the required data and collection methods. AI standards also formalises the quality and accuracy of different types of AI, which includes considerations for the criticality of assets or asset systems and the criticality of the decisions based on AI (IAM, 2015).

AI systems range from sophisticated all-inclusive Enterprise Asset Management (EAM) software to hybrid mixes consisting of various software applications. These systems are used to gather, process, store and analyse AI. Across an asset's life different entities have an interest in the asset, each stage with distinct AI needs (IAM, 2015). Ladley (2010) argues that although information is an asset, it is also an abstract concept and must thus be managed different from tangible assets, people and processes. The AI system should manage AI content to minimise risk and cost due to unnecessary data, content misuse, inferior processing and contravention of statutory requirements. However, achieving the optimum AI mixture is difficult as there is often no clear division between AI systems and other EAM systems due to the wider use of information for other functions within an organisation (IAM, 2015).

"Organisations involved in the management of assets rely on asset data and information as key enablers across the breadth of asset management activities" (IAM, 2015). These organisations should thus assess their AI quality and make plans to improve where required. Data gathering, as well as data and information management, have a cost and it could be decided by an organisation that the costs involved in gathering the data and information are not worth the benefits. The ISO 8000 series of standards is dedicated to providing guidance on data and information quality, as well as the importance of linking organisational objectives to AI. According to ISO 8000–8 (2015) information and data quality are characterised as follows:

Syntactic quality: This is the degree to which data conforms to the specified syntax, or requirements stated by metadata (syntactic rules). For example, violation of criteria by alphabetic characters found in a numerical field and duplicate entries.

Semantic quality: The measure to which data relates to what it represents.

Pragmatic quality: The is the measure of suitability or importance of data for a particular purpose.

Minnaar (2015) developed a framework to help asset managers to identify pragmatic data quality issues. This was achieved by using a comprehensive literature review followed by a case study in the mining environment. The framework was developed using a top-down approach – the decision is the end goal of data – and has three components to the solution: a data pipeline model; a software tool; and guidelines of how to use the software tool. The basic premise was the development of a software tool for decision-makers to identify gaps in data, which is required for decision-making. Unfortunately this study did not value the missing information which would enable a ranking of relative importance being assigned to the missing pieces of data or information. IAM (2015) states that organisations do not typically have the quality or quantity of AI to be adequate, creating a requirement to assess and prioritise critical areas in AI as an input to AM decision-making.

Integrated logistic support (ILS) is a subset of AM and defined as: "an integrated and iterative process for developing material and a support maintenance strategy that optimises functional support, leverages existing resources, and guides the system engineering process to quantify and achieve high performance with lower life cycle cost" (Podofillini *et al.*, 2015). A series of specifications on ILS is available, termed the S-Series, with the vision of standardising logistic processes so as to enable data sharing and exchange over various life cycle stages of a product (SX000i, 2018). The connection of data availability to the applicable stakeholders is key to achieving one of the objectives of the series: to optimise life cycle costs as well as the performance of the product (SX000i, 2018).

The need for good AI is increasing, requirements are becoming more advanced, the number of stakeholders, and subsequently the complexity of combining and sharing information, is growing (IAM, 2009).

In the context of AM, the IAM (2015) states that AI typically includes:

- Records of physical assets, known as an asset inventory or asset register;
- Asset attributes, e.g. model, serial number, capacity;
- Asset system attributes, e.g. capability;
- Spatial information, location, dependencies and connectivity information;
- Logical groupings, e.g. equipment types, zones, systems;
- Access requirements, e.g. safety related information, permits, right of way;
- Asset performance information, subjective or objective, which also covers areas such as condition, serviceability, reliability;
- Historical records or work carried out or past events such as breakdown repairs;
- Documents, design models, drawings, and photographs.

Although there are small differences, the areas from which AI must flow according to ISO 55002 (2014) aligns with those stated above:

- Strategy and planning, e.g. objectives, demand plans;
- Process, e.g. asset-related processes and procedures, process performance indicators and objectives;
- Technical and asset physical properties, e.g. attributes, ownership, location, condition, in-service date, design parameters;
- Service delivery and operations, e.g. performance objectives, asset performance characteristics, service levels, future operational requirements, demand objectives;
- Maintenance management, e.g. historical asset failures, future maintenance requirements, replacement dates;
- Performance management and reporting, e.g. continuous improvement objectives, regulatory reporting, asset performance data;
- Financial and resource management, e.g. historical cost, asset replacement value, date of acquisition, life cycle costing analysis;
- Risk management;
- Contingency and continuity planning;
- Contract management, e.g. vendor information, asset related contractual information, service objectives;

In determining AI needs organisations should appraise the following ISO 55002 (2014):

- The value of the information in decision making and the quality relative to the cost, complexity, processing, managing and maintaining databases;
- The need to align its AI requirements to suit or manage the asset's risk level;
- Stakeholder participation in determining the types of AI required;
- Determination, assignment and periodic review of accountabilities for specific AI;
- Competencies required to collect, interpret, utilise and report AI;
- Aligning AI with different levels and functions in the organisation (vertical as well as horizontal across fields);
- Aligning financial and non-financial terms;

- Financial information regarding assets must be appropriate, consistent, traceable and be realistic of the technical and operational status of assets;
- Data flow and AI integration within the organisation;
- Maintaining quality and timelessness of AI.

Eweje *et al.* (2012) stated that during a study conducted on mega-projects it was found that information feed to the project managers significantly influenced the value created by the mega project. A correlation was found between the quality of the decision-maker's decisions and the quality and quantity of information available. This again directly relates to performance and delivering strategic value (Eweje *et al.*, 2012). One of the recommendations of the study is that information feed design should be risk based, linked to the strategic value lost or gained. The study by Eweje *et al.* (2012) is set in the planning and acquisition life cycle stage of products, which is before the operational deployment and maintenance being considered in this thesis. However, their insights into information feed for decision-making is applicable across life cycle stages and industries.

2.1.4.5 Organisation and people

Managing change, especially changing traditional views or establishing a new organisational culture towards the AM way of thinking, can be uncomfortable for people, but must be done sooner rather than later according to IAM (2014). The subjects in this group are interconnected and influence the performances and behaviours that achieve AM objectives (IAM, 2015). It is important to invest time and effort into them as the ability of an organisation to adopt and embed AM into the organisational culture is controlled by these subjects.

The organisation and people group consists of the following subjects (IAM, 2015):

1. Procurement & Supply Chain Management;
2. Asset Management Leadership;
3. Organisational Structure;
4. Organisational Culture;
5. Competence Management.

2.1.4.6 Risk and review

In any management system risk and review are elemental for sustainability (IAM, 2014). In AM, most of risk and review involves constantly analysing the cost-risk trade-off by identifying, understanding and management of risks (IAM, 2015). This, together with the evaluation and analysis of performance and organisational objectives and outcomes over various life cycle stages, is then used as inputs to the Strategy and Planning and AM decision-making subject groups (GFMAM, 2014; IAM, 2015). Berenyi (2014) states that in order to demonstrate the desired balance between cost, risk and performance the following, should be considered:

- Risk is expressed as the associated residual risk with the expected asset performance, which should be based upon the overall risk approach and in line with AM decision-making criteria.
- Cost is normally expressed in monetary terms, where monies must be paid for enabling cost (such as energy) or mitigating cost (such as maintenance, spares and tools).
- Performance is normally expressed in quantitative terms such as RAMS parameters over an agreed time frame as well as a functional performance specification (asset attributes such as speed and power).

What is important in determining if the AM system is fit for purpose is the identification of critical measures that clearly link to organisational objectives and the assessment of the extent to which the organisation is following the processes and decision making criteria set by the AM system (GFMAM, 2014). The strategy and planning group consists of the following subjects (IAM, 2015):

1. Risk assessment and management;
2. Contingency planning resilience analysis;
3. Sustainable development;
4. Management of change;
5. Asset performance and health monitoring;
6. Asset management system monitoring;
7. Management review, audit and assurance;
8. Asset costing and valuation;
9. Stakeholder engagement.

2.1.5 AM system

Operating within the wide scope of AM and achieving its objectives "requires a system of direction and control – a management system" (IAM, 2015). ISO 55000 (2014) defines an AM system as: "a management system for asset management whose function is to establish the asset management policy and asset management objectives" as well as the processes needed to successfully bring about the stated objectives. The hierarchical relationship for the management of assets is shown in Figure 2.5.

The AM system should be seen as a set of tools that are integrated to ensure delivery of AM activities (ISO 55000, 2014). These tools include "policies, plans, business processes and information systems", but ISO 55000 (2014) cautions that although AM requires accurate AI, the AM system is more than an AI system. The AM system is meant to integrate activities and contributions of functional units within an organisation that would otherwise have functioned in isolation. In order to establish and operate an AM system requires in-depth understanding of the policies, plans and procedures of each element of the AM system.

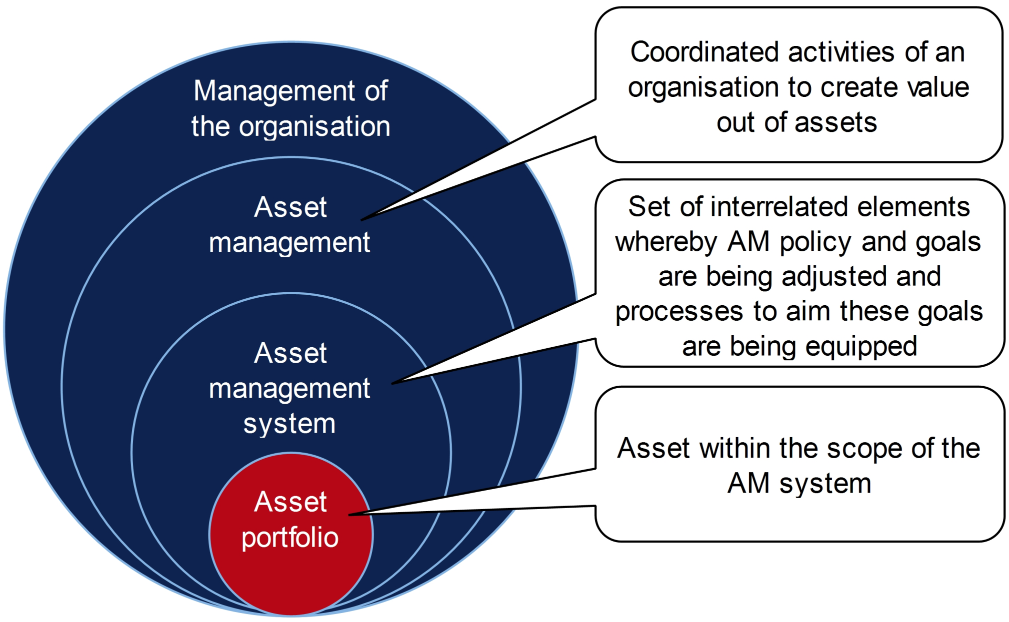


Figure 2.5: Relationship between assets, asset management system, asset management methodology and the management of the organisation (Adapted from ISO 55000 (2014))

2.1.6 AM system elements

According to ISO 55001 (2014) there are seven elements of importance, or requirements, in a management system for Asset Management. IAM (2015) explains that these elements are aligned with the ISO management system for AM, and should an organisation's overall management system not be aligned to general ISO principles, the ISO 55000 series cannot be expected to function effectively when bolted on. In the context of this thesis, AI is seen as an asset to the organisation. As with other assets that are managed by the AM system, AI is managed by its own system. Ladley (2010) states that information AM is the procedure that contains fundamental concepts to manage information as an asset. He explains further that enterprise information management (EIM) is the programme to manage data and information as assets. EIM is, however, not often operated in isolation, but typically forms part of the greater EAM system of the organisation due to AI's links to other assets as well as being a fundamental element in AM as a whole. When researching AI it is thus important to consider the elements of the information AM system as part of the greater AM system.

The AM system elements can be grouped around the PDCA cycle as can be seen in Figure 2.6 (Van den Honert *et al.*, 2013; IAM, 2015). The representation is based on the greater AM system, but the concepts can be applied to the information AM system as explained in the following sub-sections.

2.1.6.1 Context

Due to its complexity, the management system's environment (context within the system and external of the organisation) provides the pivotal basis from which the other elements of an AM system will validate their influence on the system in which they exist (ISO 55000, 2014). Factors to consider when determining the context of the AM system are (ISO 55000, 2014):

External factors
: Social, economic, cultural, physical, regulatory and financial constraints.

Internal factors
: Organisational culture, nature and purpose of the organisation. Key to consistent decision making are the needs, expectations and influences of stakeholders.

The scope of the management system must be delineated in terms of the above-mentioned factors, as well as the interaction with other management systems in the organisation (ISO 55001, 2014). The scope, together with expected outputs, should be used to determine the appropriate approach in realising organisational objectives.

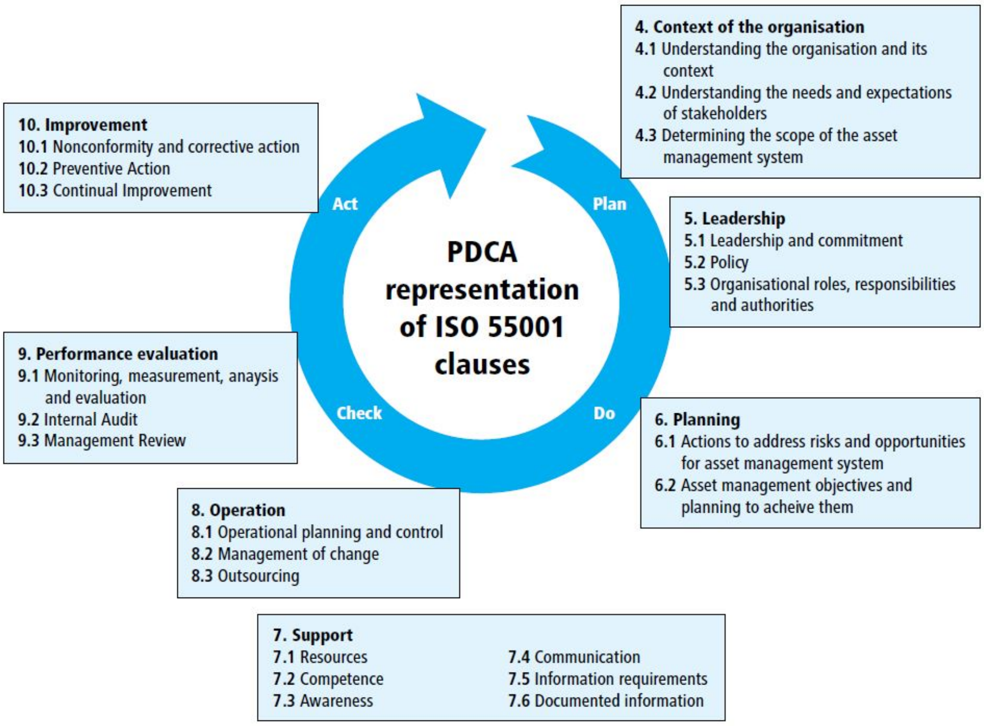


Figure 2.6: A visual representation of ISO 55001 AM system requirements superimposed on the PDCA cycle (Adapted from IAM (2015))

2.1.6.2 Leadership

Top management must ensure commitment to the management system by leading, directing and supporting personnel within the organisation to function within the set guidelines as well as contributing to better any aspect of the management system (ISO 55000, 2014). Leadership must furthermore ensure that the correct policies, strategies, resources, organisational roles and authorities are put in place to ensure that the management system integrates with other aspects of the business, and vice versa (ISO 55001, 2014). Commitment from leadership and collaboration between top management is essential to enable various departments within the organisation to operate seamlessly as one with a common goal: To achieve the mission of the organisation (ISO 55000, 2014).

2.1.6.3 Planning

Organisational objectives are commonly captured in an organisational plan, which is a higher level document than the asset management policy and strategic asset management plan (ISO 55000, 2014). Planning should address risks, continuous improvement, opportunities and measurable objectives within the context of the organisation in addition to the expectations of its stakeholders.

Asset management and information management objectives should be set up whilst considering higher-level objectives, policies, strategies and integration of all relevant departments within the organisation. Decision-making criteria, processes and methods that will be used to manage assets must be specified when planning how to achieve the objectives (ISO 55001, 2014). These objectives must be transparent and revised as required.

2.1.6.4 Support

The resources required for the "establishment, implementation, maintenance and continual improvement" of the organisation's management system must be identified and provided to ultimately meet the set out objectives of the AM system (ISO 55001, 2014). The AM system's objective is coordinating interrelated elements in order to achieve AM outcomes (see figure 2.5). The management system must bring about an efficient relationship between various, and often shared, resources by applying and improving their use (ISO 55000, 2014). This is managed by AM plans. ISO 55000 (2014) states that the AM system provides information to evaluate the effectiveness of AM plans, managed by AI systems. Due to the complexity and vastness of AI systems in some organisations numerous stumbling blocks are experienced when "collecting, verifying and consolidating asset data in order to transform it into asset information" (ISO 55000, 2014).

A process regarding the management of AI must be put in place by the organisation. The process should ensure that the legal, statutory, stakeholder and organisational objective-related requirements in terms of information and data are met (ISO 55001, 2014). The information needed to support assets must be identified, acquired, collected, securely stored and made available when required (ISO 55001, 2014). Current and future support requirements must be assessed regularly. It is easy to advocate that information is valuable, but it is difficult to quantify and deliver the perceived value of information in supporting organisational objectives (Ladley, 2010)

2.1.6.5 Operation

The organisation should take positive control of the AM activities' direction, implementation and operations. This includes planning, execution, corrective actions and managing change to mitigate risks (ISO 55000, 2014). Furthermore, measures must be put in place to ensure that any outsourced work is still governed by the AM system, even though this will increase complexity (ISO 55000, 2014).

2.1.6.6 Performance evaluation

Organisations should assess the performance of assets, management systems and AM, despite the evaluation often being complicated and indirect (ISO 55000, 2014). According to ISO 55000 (2014) the key to effective performance measurement is effective asset data control and the subsequent translation into AI. Monitoring, analysis and evaluation of AI should be an ongoing process performed on all assets, internal and outsourced (ISO 55000, 2014).

The organisation should decide what must be examined and evaluated, as well as how it should be done in order to provide information on the performance and efficiency of assets and their management ISO 55001 (2014). The intention is to verify whether AM objectives have been achieved or not. Reasons for failure to achieve, or exceeding expectations, should be studied and acted upon in such a way to derive benefit for the organisation (ISO 55000, 2014). The organisation should furthermore carry out an internal audit to check for non-conformities with regards to non-negotiable international, national standards, policies and legislation (ISO 55001, 2014). Using the outcome of evaluations and audits, top management should review the management system at regular intervals to ensure that it is still suitable and performs as intended (ISO 55000, 2014).

2.1.6.7 Improvements

Continuous improvement should be applied to assets, the management system and AM activities, even in the context of a complicated and constantly evolving environment (ISO 55000, 2014). Opportunities should be sought through inputs from performance evaluation, internal audits and assessments of emergency situations (ISO 55000, 2014). Non conformities and emergency situations require corrective or preventive actions (ISO 55002, 2014). Potential asset-related incidents must be identified and the appropriate action taken to prevent them. Where a nonconformity is identified, or an incident occurred, the organisation should take action to remedy its immediate effects, if required, and also eliminate its causes by changing the management system (ISO 55002, 2014). All improvement actions must be risk assessed before being implemented (ISO 55000, 2014).

2.1.6.8 Other elements

IAM (2015) states that although the effectiveness of ISO standards are often questioned, the standards can be very effective when aligned and integrated with the organisation's overall management system. The ISO 55000 series of standards management system clauses were superimposed over the PDCA cycle by IAM (2015) (see Figure 2.6), but it is stressed that the PDCA cycle does not prescribe the sequence in which the requirements must be implemented, nor their importance. Should the Lean or Six Sigma approach be adopted by an organisation, the PDCA cycle will not be followed, but the seven requirements can still be used to provide direction and co-ordination in effective management of assets (IAM, 2015).

An AM system is a subset of the greater AM landscape (see Figure 2.5), where AM at its core consists of the AM fundamentals and AM subjects (GFMAM, 2014). The AM system and the interrelated IAM system have seven elements as denoted by the ISO 55000 series of standards. Further elements can be derived as it befits the organisation's needs. The fundamentals, subjects and elements work in combination with each other to realise value from assets and meet organisational objectives.

2.2 South African Navy

> *"The sea is of vital national interest, and that is why we maintain a navy. Just as we believe all people should be free, so too, as a nation, we believe in the freedom of the seas. That is a matter of national strategic interest. We are a maritime nation trading all over the world."*
>
> *– Nelson Mandela*

In this section a background of maritime security is provided, followed by an introduction to the operating environment of the SAN. To provide further insight and context AM and AI in the SAN are reviewed.

2.2.1 Maritime security and the role of the South African Navy

Maritime security is a buzzword that surfaced fairly recently in the international community, yet without consensus on the proper definition of the term (Bueger, 2015; Potgieter, 2009). The term does, however, draw attention to new challenges and the evolving nature of threats in the maritime domain. Bueger (2015) placed typical concepts related to maritime security in a matrix that explains what it could encompass (see Figure 2.7).

Typically navies are concerned with the national security elements whereas the coast-guards are concerned with the criminal elements of maritime security that take place in domestic waters such as smuggling, drug trafficking, pollution and illegal fishing. However, these lines have been blurred as dimensions of regional, continental and global security have been added as items of critical importance to domestic security (Potgieter, 2009). Some countries do not have

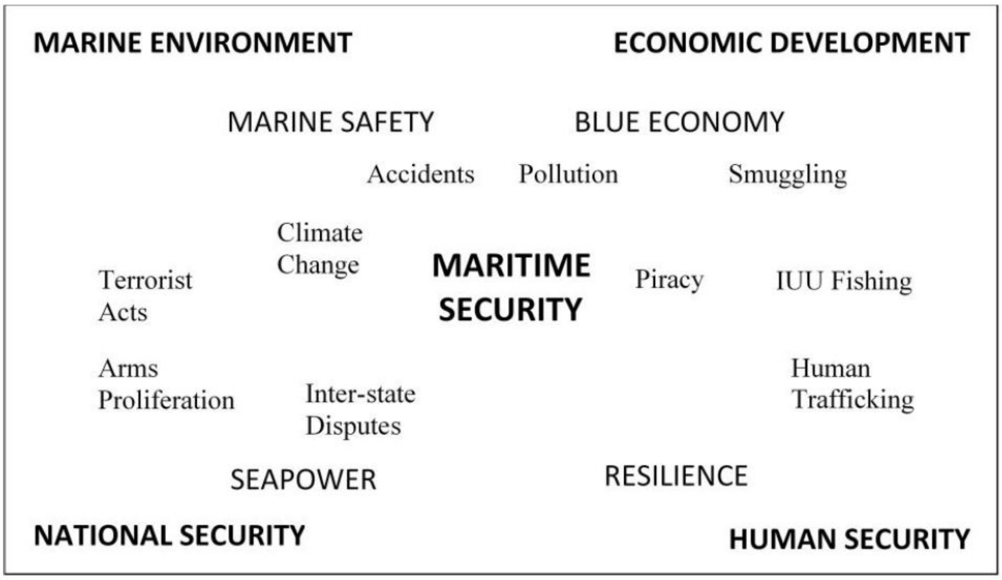


Figure 2.7: A maritime security matrix adopted from Bueger (2015)

the resources to maintain regional security and rely on others to assist. An example is countries like the United States of America, the United Kingdom and France entering the territorial waters of Somalia in 2008 – with the blessing of the interim government and the UN security council – to repress acts of piracy (Potgieter, 2009).

South Africa's economy is maritime dependent and there are various maritime interests that need protecting. The constitutional mandate of the South African Department of Defence (henceforth referred to as the DOD) remains safeguarding of the borders to defend and protect the Republic of South Africa, although no international armed conflict threat is anticipated against South Africa for the foreseeable future (Mapisa-Nqakula, 2016). The policy adopted by the DOD however dictates that the SAN must maintain a credible deep-ocean and versatile littoral capability, at this stage mainly for deterrence and interdiction (Mapisa-Nqakula, 2015). Where the SAN is most active at this stage is in supporting maritime security in the Southern African Development Community (SADC) region (Mapisa-Nqakula, 2016). The defence and security of South Africa is inextricably linked with that of the southern region and the continent of Africa. South Africa does not have a coast-guard, nor long-range maritime patrol aircraft that can assist. As such, maritime security as a whole has mostly been allocated to the SAN (De Wet, 2009).

South Africa requires a balanced maritime capability to effectively respond, when required, to any maritime security threats that may arise. The capabilities embedded in the force design of the SAN and greater SANDF have to evolve to stay ahead of following trends: more complex intervention environments, the ever-increasing significance of information and information security, technology innovation, rising costs of weaponry and the expansion of battlefield boundaries. Force design strategies are influenced by political, economic, social, technological, legal, physical and internal environments. Military capabilities are guided by policy, and created with a formal process that ensures adherence to strategic operational concepts to be in support of the influential environments listed above (RSA Department of Defence, 2003; Mapisa-Nqakula, 2015).

South Africa's defence force is in a critical state of decline due to underfunding (Mapisa-Nqakula, 2015). Measures to rectify the situation are in place, with the following planning milestones as foundations (Mapisa-Nqakula, 2016):

1. Arresting the decline.
2. Re-balance and re-organise the defence force.
3. Create a sustainable defence force.
4. Enhance the defence force's capacity to respond to emerging threats and challenges.
5. Defend the Republic against threats.

Currently the focus is on achieving the first milestone. As part of achieving the first milestone it is required to address key areas such as cost-driven interventions to improve the efficiency and effectiveness of the SANDF, as well as funding interventions for capabilities that are required to support existing commitments. The current global and South African economic climate of slow growth adversely affects defence budget allocations, resulting in a disconnect between the government's level of ambition of achieving the above milestones and the current budget allocation (Mapisa-Nqakula, 2016). The implication is that the defence force must do things differently to achieve the required outputs with less resources.

The core outputs of the SAN and associated performance indicators are (Mapisa-Nqakula, 2016):

1. Conduct ordered defence commitments in accordance with government policy and strategy, measured by number of hours at sea.
2. Provide mission ready defence capabilities, measured by percentage compliance with joint force employments requirements.

The capabilities required are all within the capabilities available from the SAN's current weapon systems (Mapisa-Nqakula, 2016). For up to financial year 2019/2020 there is thus no need for the acquisition of new military hardware and systems; the performance indicators are only affected by the operation and maintenance of the current systems.

Even with its limited resources the SAN has undertaken to enhance maritime security. South Africa is one of the major economic powers of sub-Saharan Africa and also one of the few African states with any noteworthy naval strength (Heitman, 2009). It has a responsibility to assist in regional maritime security, but also self-interest when creating an environment in which to develop its economy.

2.2.2 AM in the South African Navy

The ability of the SAN to comply with the above outputs requires assets, which are mostly large-scale systems, to be operational. "A ship is classified 'operational' by its operating authority once it is capable of fulfilling all its assigned roles in a hostile environment" (South African Navy, 2000). Being declared operational has specific requirements such as correct manning, work-up training for emergencies, correct combat capabilities as well as having no operational defects (OPDEF). An OPDEF is defined as: "a defect which significantly limits, or may limit the combat or sea keeping capability of a vessel and may cause danger to the safety of a vessel or its personnel" (South African Navy, 2013). There is a value system in the SA Navy regarding OPDEFs and the following is applied:

> "The decision whether a defect can be classified as an OPDEF must be measured by the *availability* of a vessel to start an operational mission, the degree to which a system is in an operable and committable state at the start of a mission when the mission is called for. Similarly a defect can be classified an OPDEF if the defect has the potential to adversely affect its *dependability* in being able to complete the mission, i.e. the degree to which a system is operable and capable of performing its required function at any time during a specified mission profile, given that the system was available at the start of the mission" (South African Navy, 2000).

S3000 (2014) states that operational readiness is an alternate term for availability and therefore provides a similar definition as given above, but adds that availability is achieved by a combination of operational system and support system performance. Reliability, or the probability of failure-free performance of a system is, according to S5000 (2016), a prime driver of support resources. Over time, availability and reliability, in combination with inherent capability, are measures of system effectiveness and fall under the risk and review group of AM subjects (Pennell and Knight, 2005; Berenyi, 2014).

The general premise of AM is to realise value from assets, which differs between organisations. In the private sector value is typically defined by the effect, directly or indirectly, on profits. However, in the public sector value is less clear. It is encapsulated by the “cost versus benefit” concept. The advantages and disadvantages of utilising resources in a specific way is weighed against the risks of not doing so. The risks include not achieving the set goals in the most effective way possible or in the shortest period of time.

AM in the SAN is abbreviated as making the best life cycle decisions, based on a clear understanding of the DOD’s long-term objectives (Uys, 2017). This correlates with the statement by ISO 55000 (2014) that AM “translates the organisation’s objectives into asset-related decisions, plans and activities, using a risk based approach”. Financial, management, engineering, operating and maintenance processes form part of the asset management system, all of which must be coordinated from the planning phase to the end of an asset’s life cycle (Schuman and Brent, 2005). The DOD adopted a system approach in its organisation, consisting of elements and sub-systems working together to provide combat-ready systems that can be deployed (RSA Department of Defence, 2003). Systems engineering (SE) and project management (PM) play an integral role in the management of the DOD, but are used predominantly in the acquisition life cycle stage. System management (SM) is more dominant during the operational deployment and maintenance as well as disposal life cycle stages, where a concerted effort is needed to preserve order in the systems created by the acquisition process (Uys, 2017). Logistic engineering (LE) forms part of the complete life cycle in the form of ILS (South African Navy, 2008). The relationships are shown in Figure 2.8.

The assets of the DOD are designed and managed to operate effectively as military capabilities, which may be used as an individual capability, or combined into a higher order military system, typically used in military campaigns (Uys, 2017). S5000 (2016) defines capability as the ability to perform a given task in a specified operational context. Uys (2017) argues that capability includes availability and reliability in that a product must be available when required and for the full duration required to be classified as capable. In addition, there must be inherent capability, which is the ability, or having the attributes required to do something. S5000 (2016) agrees with the concept, but uses combat capability to describe the collective of inherent capability, availability and reliability. The definition of the terms differ slightly in literature, but the concept that inherent capability, availability and reliability combine to provide a mission-capable system required to achieve organisational objectives remains constant.

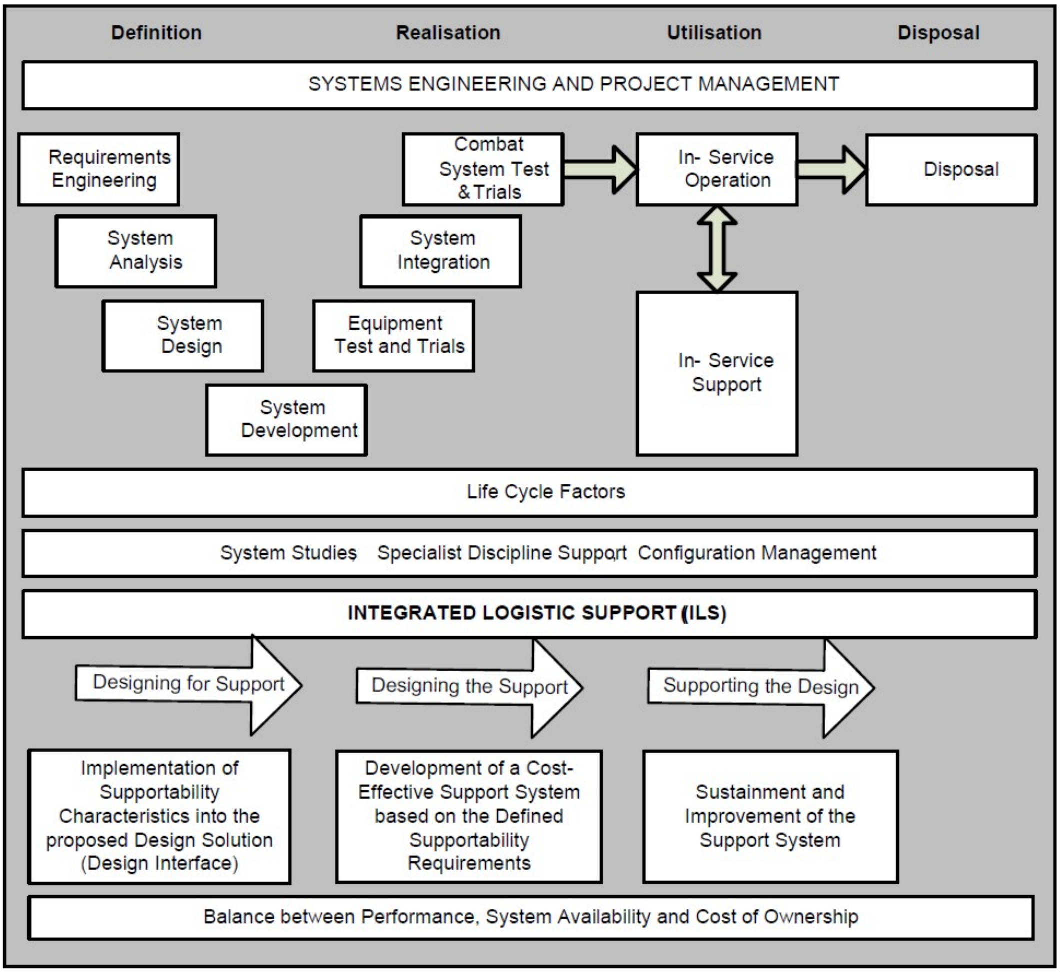


Figure 2.8: System engineering and ILS interface (Adapted from South African Navy (2008))

Reliability is the probability of a product performing as intended over a period of time, which, together with inherent capability, is instilled in the design phase of a system as per specification (US Department of Defense, 2005; S5000, 2016). Inherent capability and reliability are verified in the initial testing and acceptance of the vessel against the design specification, and are typically not revisited unless inferior performance or multiple failures during missions necessitates redesign of the physical system or its support concept (South African Navy, 2008). Availability is also a design consideration, but is carried forward into the operational deployment and maintenance phase as operational availability, one of the overall performance metrics for systems operating in the field (US Department of Defense, 2005). Inherent availability is the theoretical value used when only design parameters are considered, whereas operational availability includes the effect of the support system as well (US Department of Defense, 2005; US Department of Defense, 1983).

In the SAN, availability and reliability fall into the domain of ILS, from design considerations during the acquisition stage to providing the required support during the operational deployment and maintenance life cycle stage (South African Navy, 2008). The influence of ILS on the life cycle of a system is depicted in Figure 2.9. During the operations and maintenance life cycle stage ILS is a subset of SM, managed by the products system manager (PSM). To contextualise SM in the SAN the four primary life cycle phases used in the DOD must be reviewed. They are: planning, acquisition, operational deployment and maintenance, as well as disposal (RSA Department of Defence, 2003).

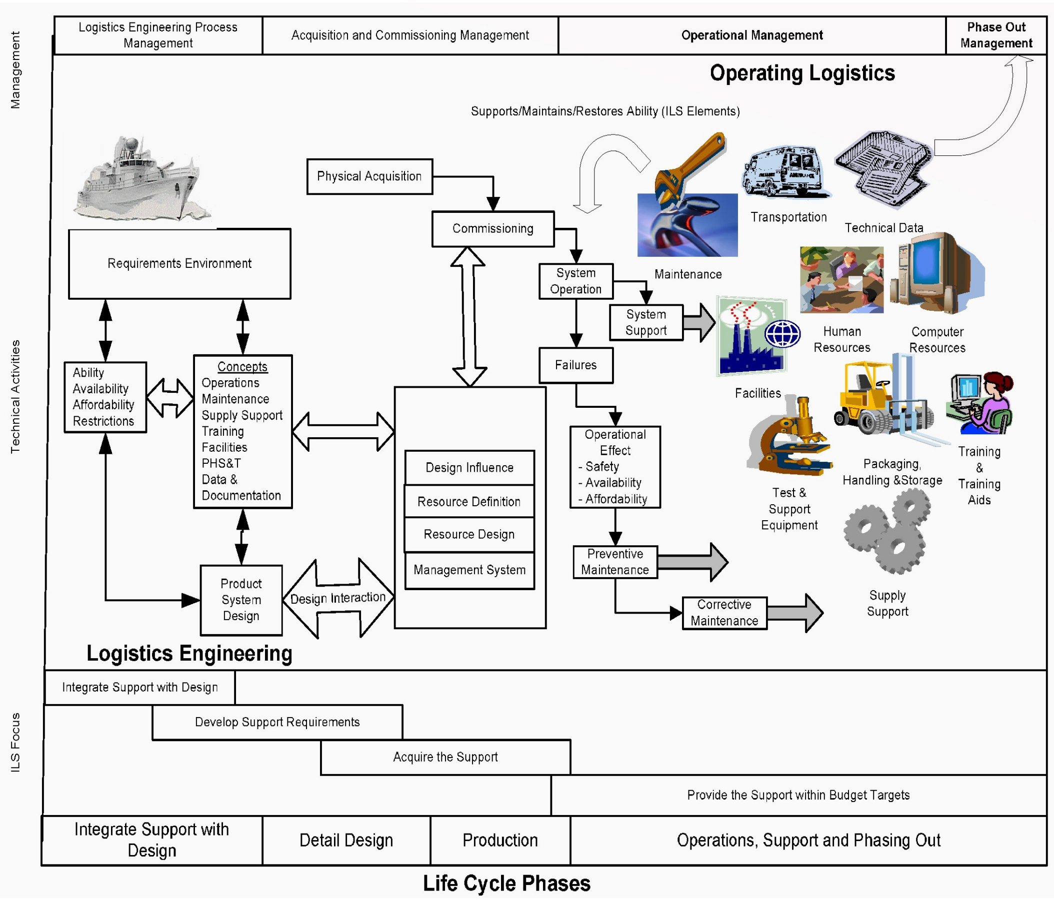


Figure 2.9: Life cycle stages and ILS (Adopted from South African Navy (2008))

In the planning life cycle stage a force structure plan (FSP) for the SANDF is produced that contains essential defence capabilities as per the long-term defence strategy (RSA Department of Defence, 2003). Each capability is prioritised and evaluated in terms of total defence capability and life cycle cost.

Cognisance is also taken of existing capabilities and their various obsolescence stages. Based on the FSP, development plans (DP) are compiled that contain required operating capabilities (ROC). The DPs and ROCs are used to initiate the acquisition phase and establish the specification baselines for combat groupings or systems (RSA Department of Defence, 2003).

During the acquisition stage verification and validation processes qualify each baseline to ensure that the system capability meets the ROC set in the planning stage (Haskins, 2011; RSA Department of Defence, 2003). At the end of the acquisition stage, in addition to the actual system, an operational support baseline (OSBL) is produced which contains all the performance, build, support and management information for the system (Sparrius, 2013; Uys, 2017). If everything is done in accordance with the OSBL during the operational deployment and maintenance life cycle stage, the operating performance of the system should meet the ROC, interface with other systems and be acceptable to the client.

SM is concerned with the management of the systems in accordance with the OSBL, but also in maintaining the OSBL should any changes be required due to obsolescence, technological advances, operational aspects, external system interfaces or redesign. In the SAN, SM takes place in the operational deployment and maintenance stage as well as the disposal stages, with influences on the prior stages (South African Navy, 2008). Typical system life cycles are driven by three aspects: business, budget and technical (Haskins, 2011). It is often not technically possible nor financially or operationally feasible to implement engineering changes (EC) in an operational system. Operational feedback information collected must thus be documented for use in the planning and acquisition phases of future systems. That is achieved with a closed loop data collection, analysis and corrective action system (see Figure 2.10).

According to the South African Navy (2008) the details of all operating and support events in the operational deployment and maintenance stage of a product system's life cycle are recorded by a reporting system and fed into the SAN's logistic information system named OSIS (short for operational support and information system). The information is used by the PSM to make decisions that seek to improve the product system's operational availability and cost-effectiveness (South African Navy, 2008). These decisions are part of a closed loop learning cycle that constantly evaluates performance, decisions as well as evolving risks and opportunities, ultimately influencing future decisions (Uys, 2017).

Strategic defence capabilities are thus realised, and defined, in the planning and acquisition life cycle stages (RSA Department of Defence, 2003). After the acquisition stage, responsibility is transferred from the naval acquisitions

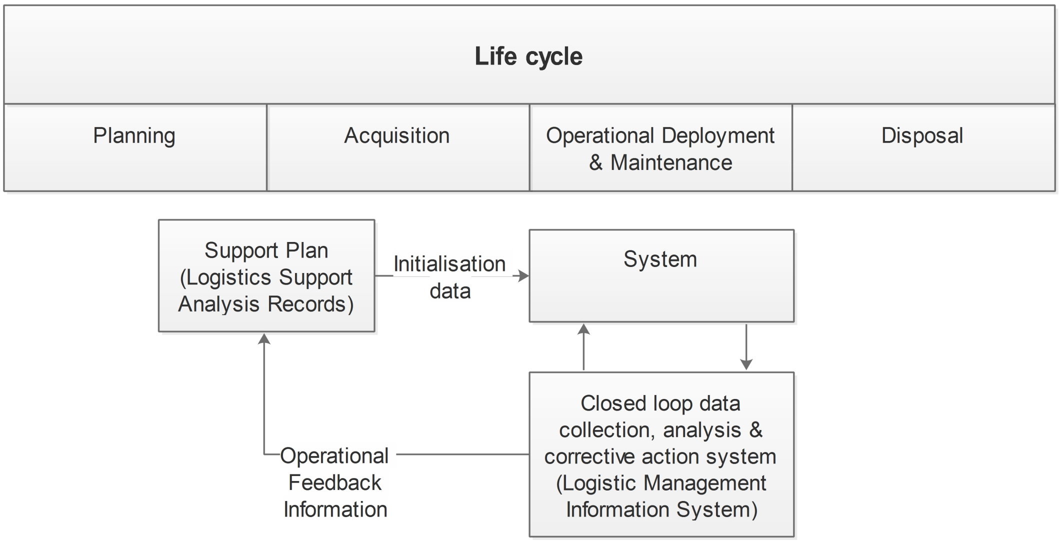


Figure 2.10: Life cycle stage database relationship (Adapted from Sparrius (2017))

directorate to the fleet command directorate where the PSM is responsible for the equipment and its OSBL during the operational deployment and maintenance life cycle stage. The PSM is to make "mission capable product systems available to the fleet commander" and ensure that the required availability levels of vessels are met at all times (South African Navy, 2008). Seen from a management perspective, AM in the SAN is divided into two main stages: acquisition management and operational management, with in-service feedback mechanisms used in the operational deployment and maintenance stage to change current systems, where feasible, or influence future designs.

2.2.3 AI in the South African Navy

Asset Information (AI) is present and important in all life cycle stages of SAN systems. In the acquisition life cycle stage the AI focus is on ensuring that the functional and logistic requirements are reflected in the engineering data. During the operational deployment and maintenance life cycle stage the focus is on ensuring that the same requirements match the actual operating data of a system (South African Navy, 2008). Data identification, structuring, capturing, processing, analysis, reporting, safekeeping, backup and archiving, the whole process of turning data into information and insight for decision support within the SAN must be managed (South African Navy, 2014).

Configuration and data management (CDM) starts at the ROC, where high level requirements are specified. To achieve these requirements, various levels of sub-requirements must be achieved. The process of baselining and putting the sequential progression of specifications, verifications and validations under configuration management is referred to as the Vee model and is shown in Figure 2.11 (Haskins, 2011; BKCASE Editorial Board, 2014). CDM during the qualification phase of acquisition, before moving to the operational deployment and maintenance stage, culminates in the qualification of the OSBL.

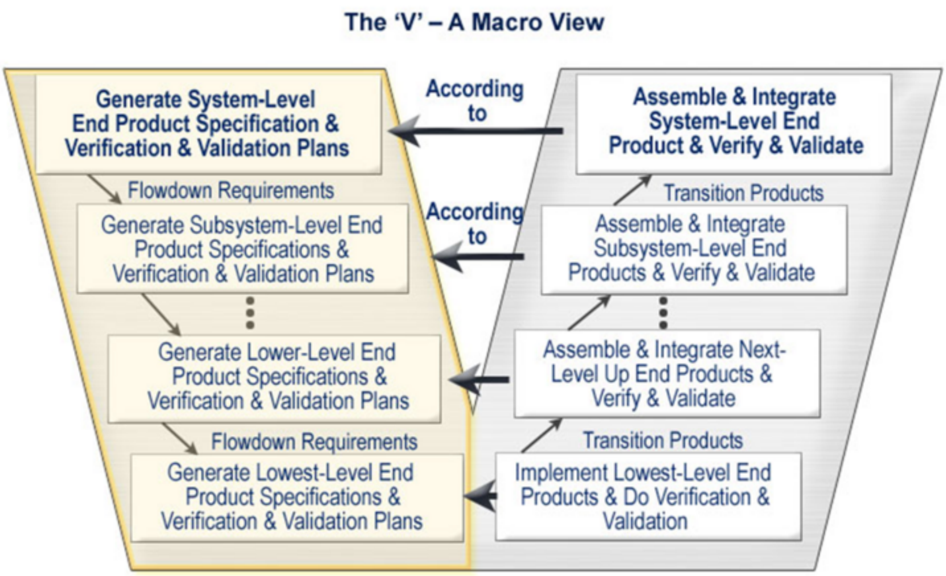


Figure 2.11: The Vee activity diagram adopted from BKCASE Editorial Board (2014)

According to the South African Navy (2008) the OSBL typically contains the following types of information:

System specification: This document defines the roles, functions, performance, interfaces and physical characteristics of the product system as well as the associated logistic support requirements. It forms the basis document against which changes affecting the operating capability of the system can be measured. The performance characteristics are allocated down to sub-system level.

Hardware definition: This category includes documents and data defining the system hardware down to maintenance significant item levels, e.g. system breakdown structure or ships' equipment list and associated equipment details.

Software definition: This defines the embedded and application software design in sufficient detail to facilitate effective maintenance and upgrades of the software.

Design documentation: Design documentation contains product information relating to the physical configuration of items such as drawings, material specifications to allow for the efficient operating, repair, upkeep, upgrade and modification of system.

Support data: This includes logistic support analysis records (LSAR), logistic specification, maintenance manuals, operating manuals and training manuals.

Statutory and general documentation: Ships typically receive classification society certification, occupational health and safety (OHS) certification, anti-pollution certification and any other statutory certifications.

Test and trial documents: This entails all the test and trial documentation for the complete system, including the results of acceptance tests done to serve as basis figures.

Products system manager plan and associated information: This document addresses the overall system management effort and could be used as input for a business plan. The plan includes planned maintenance documentation, maintainer qualification and training requirements, special facilities, tools or test equipment requirements, supply details, ILS plan and disposal information.

Production and construction documentation: This document contains details of specific processes, such as welding or preservation procedures, to allow the upkeep of the system.

System specific quality documentation: The quality assurance plan and trial results are included in this section.

System specific disposal plan: The plan describes disposal requirements for the complete system.

Interim support contracts: This includes details of support contracts and service level agreements.

As part of the handover between the acquisition phase to the operational deployment and maintenance phase the applicable OSBL data is transferred to OSIS. It is the primary driver of logistics information at all SAN units. OSIS is an integrated logistic information system and is designed to maintain transactional data and does not replace the data management process, but forms the basis of configuration management, maintenance planning, materiel accounting and operational planning (South African Navy, 2008). It will, however, support the data management process by capturing and consolidating data to provide information to the PSM. Examples include system structures and associated part and serial numbers, maintenance task details, failure data, location of equipment, spares details and requirements forecasting (South African Navy, 2013).

The accumulation of the data, via transactional and management reporting, should provide the PSM visibility of deviations from the OSBL. Managing the deviations may result in ultimately amending the current OSBL (South African Navy, 2008). When the OSBL is qualified the actual system must operationally tested (South African Navy, 2008). Haskins (2011) states that there are four system verification test categories:

1. Development test – demonstrates the proof of concept or feasibility of new items.

2. Qualification test – proves that the design of the system meets, or exceeds, specification requirements.

3. Acceptance test – carried out to prove system performance, typically before handover from supplier to acquirer.

4. Operational test – the system is subjected to the actual operating environment to verify that it meets, or exceeds, specification requirements.

During the qualification phase of the OSBL deviations affecting the performance of the system must be continuously monitored and corrected to sustain system readiness objectives (South African Navy, 2008).

2.3 Systems engineering

Systems engineering (SE) is important to this research because of the DOD's system approach to the management of assets. To contextualise SE with respect to this thesis, a brief introduction to SE and systems are provided: Foundation of Systems Engineering; Systems; Tailoring; Systems Thinking; Complex Systems; and Systems Engineering in Context.

2.3.1 Foundation of systems engineering

The history of Systems Engineering (SE) can be tracked along with the evolution of human challenges. The BKCASE Editorial Board (2014) offers a brief account of how ancient emerging cities in the Middle East, Asia, Latin America and Egypt were required to provide certain functions to their citizens. Some of these functions included storage of food and emergency supplies, provision of water, preparation for the afterlife and support of trading. This required holistic planning and organisational skills; this was the start of integrated thinking.

In the Roman Empire the word "Architecture" included heating, aqueducts, landscaping, surveying and city planning, not just buildings. Architecture was used in building the megacities, and mobile cities in support of the military (BKCASE Editorial Board, 2014). Thus systems for civil and military challenges were developed.

In the nineteenth century the industrial revolution resulted in a wave of new machines that required innovative creation and sustenance. This was followed by large-scale enterprises such as the Ford Motor Company's production line for the famous Model T vehicle. However, at this time industry was not very concerned with the prevention of failures, equipment was simple and in general over-engineered. A policy of "fix it when it broke" was adopted as downtime did not matter much (Moubray, 1992).

Alessi *et al.* (1995) acknowledges the ancient application of a form of SE, but argues that the actual early development of modern day SE only started in the lead-up to World War II. That time period saw the dire consequences of failures, increased mechanisation and demands for delivery. All of these industrial demands had to be met with a drop in available manpower due to the war effort, leading to complex problems never experienced before.

The military's need for solving complex problems during World War II sparked an exponential evolution for SE. This included operations research into submarine warfare and the development of new systems such as the intercontinental ballistic missile and the nuclear submarine during the 1950s (Alessi *et al.*, 1995). So complex were these that it required structured methods to firstly understand what was needed, and thereafter develop integrated solutions.

The next significant step for SE happened during the Russian space achievements and the Cold War. Investment in research and development of military defence systems was a high priority in most countries (BKCASE Editorial Board, 2014). Although the problems arising were primarily military in nature with the military administratively in control, the solutions were procured from particular civilian contractors who operated independently. Solutions generated from isolated islands of thought often resulted in one solution interfering with another. This led to a drive from the military in standardising of products in accordance with work breakdown structures (WBS) in an attempt to facilitate effective communication between solution providers (BKCASE Editorial Board, 2014).

In 1960 software was responsible for 8% functionality of a military aircraft, in the year 2000 the figure rose to 80% (BKCASE Editorial Board, 2014). A response to this challenge was the development of model based systems engineering (MBSE) that is better suited to manage complexity than the traditional document-centric approaches (BKCASE Editorial Board, 2014). In recent times, demands increased the scale and functions not only of systems, but also the system vulnerabilities. Assessing and integrating technology in systems, which itself consists of systems, presents further challenges to the higher-level systems being engineered. Examples are progressive projects to realise the Internet of Things by creating smart hospitals, services and cities. These promise increased quality of life, but are challenged by incompatible objectives, assumptions or immature technology of the subsystems or elements that have to be incorporated (BKCASE Editorial Board, 2014).

SE is continuously needed more, but also increasingly tested. Alessi *et al.* (1995) state that there is a reason for the difficulty being experienced by industry in effectively applying systems engineering to complex problems. The explanation is that it is relatively easy for one individual to increase the expertise isolated to a certain field. This is in comparison with the challenges experienced when two or more individuals are charged with coordinating and integrating outcomes from various fields. BKCASE Editorial Board (2014) states that the human element and service-orientated requirements changed the SE field from the traditional prespecified requirements, hardware orientated with sequential steps (also referred to as the hard approach) to a softer SE approach. Soft SE is characterised by BKCASE Editorial Board (2014) as having: "emergent requirements, concurrent definition of requirements and solutions, combinations of layered service-orientated and functional-hierarchy architectures, heuristic-based solutions, and evolutionary system development".

Haskins (2011) defines SE as: "a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at the problem in its entirety, taking into account all facets and all the variables and relating the social to the technical aspect". This is, however, not the only definition of SE found in modern literature, with no one set of laws governing the discipline. According to Alessi *et al.* (1995) it is unclear if SE is a management discipline or a technical discipline that warrants its own department in a company, or if it is a process applied by all employees. Haskins (2011) describes SE as: "a perspective, a process and a profession". An AM orientated definition of SE, that is applied in this research, is given by Berenyi (2014) as: "an interdisciplinary engineering management process to evolve and verify an integrated, life cycle balanced set of system solutions that satisfy customer needs".

Modern day SE evolved over time into a complex and specialised field with several definitions that are all representative. Common term,s such as: interdisciplinary, interacting, iterative, socio-technical, integrated and wholeness correlate in literature written on SE. This points to an overlap with AM (Haskins 2011;ISO 15288 2008;BKCASE Editorial Board 2014).

2.3.2 Systems

SE is based on systems thinking and uses the systems approach as a means to realise successful systems, where a successful system satisfies the needs of the parties involved (BKCASE Editorial Board, 2014). This supports the definition of a system according to Sparrius (2013) as “everything and anything that may be needed to satisfy the user’s stated, implied and ever-changing requirements”. ISO 15288 (2008) and Haskins (2011) correlate with this definition as they state that a system is: “a combination of interacting elements organised to achieve one or more stated purposes”. The elements of such a system may be all or any combination of information, facilities, humans (operators and maintainers), supplies/materials, processes, equipment, software, hardware and/or training (Haskins 2011; ISO 15288 2008).

As with SE, there are multiple definitions of a system, which can leave a reader perplexed. ISO 15288 (2008) simplifies the matter by explaining that the definition of any particular system is dependent on the observer’s interests and responsibilities. It is thus a matter of context, “one person’s system-of-interest can be viewed as a system element in another person’s system-of-interest” ISO 15288 (2008). This reiterates what ISO 55000 (2014) states about the *context* element of an asset management system (see Section 2.1.6.1).

BKCASE Editorial Board (2014) states that there are three overall categories of systems: engineered, natural and social (see Figure 2.12). SE centres around the engineered system, but the engineered system is influenced by the natural and social system of which a thorough understanding is needed. Correspondingly, El-Akruti and Dwight (2013) reason that an AM system exists on three levels within an organisation:"Strategic, tactical or aggregate, and operational". Regardless of how boundaries to define the system of interest are chosen, SE concepts allow a practitioner to tailor individual cases for the purpose required.

2.3.3 Tailoring

System engineering ensures the technical integrity of an item throughout its life cycle, where SE standards aid communication between stakeholders by defining generic practices that might or might not apply during a system’s life cycle (ISO 15288, 2008; Haskins, 2011). However, applying all the formal procedures all the time is unnecessarily costly and increases the risk of exceeding time constraints. Similarly inadequate efforts typically increase risks. For the

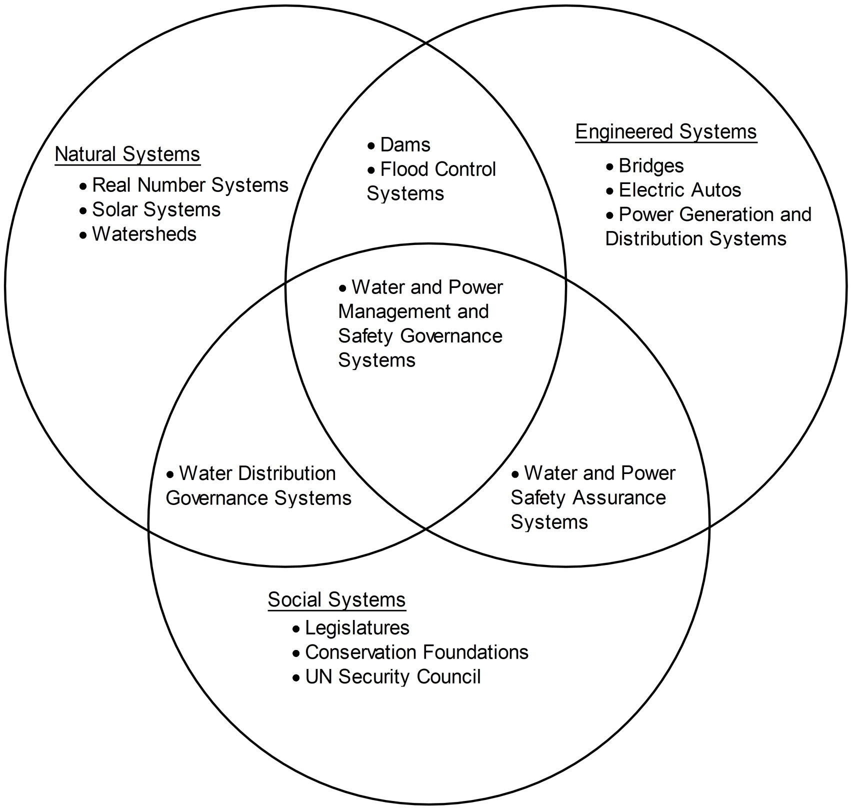


Figure 2.12: System boundaries of natural, social and engineered systems (BKCASE Editorial Board, 2014)

purpose of this thesis only the basic premise of tailoring is reviewed, which is encapsulated in Figure 2.13[2].

2.3.4 Systems thinking

Systems Thinking is the binding element of SE. Maani and Maharaj (2004) conducted a study which affirmed that there are causal links between systems thinking and complex decision-making. They reported that whilst the extent of systems thinking mattered, certain types of systems thinking are linked to superior performance. The types of systems thinking researched during the study were (Maani and Maharaj, 2004):

Dynamic thinking: This allows an issue to be formulated in respect of behaviour over time. This implies that one has to put the present state in the context of a timeline. There should thus be a historical, current and projected future path.

[2]For further reading regarding the full process of tailoring it is recommended that Haskins (2011) and ISO 15288 (2008) be consulted.

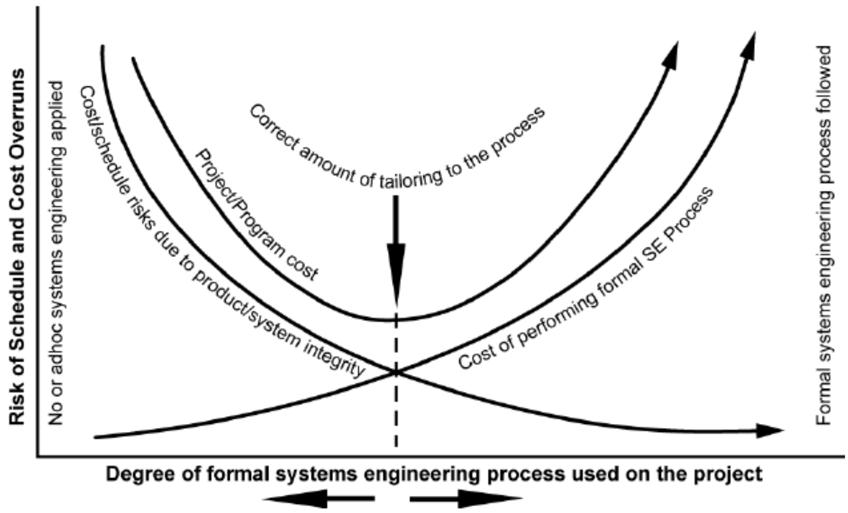


Figure 2.13: Formal process vs risk illustrating the need for tailoring (Haskins, 2011)

System-as-cause thinking: This builds on dynamic thinking. This thinking allows for the establishment of feasible explanations for the behaviour sequences as per dynamic thinking. System-as-cause thinking regards a system's behaviour as a result of the system, whilst ignoring relationships that are not under the control of decision-makers.

Forest thinking: When clearing paths from various origins to a central location through a forest, the proverbial forest thinker will be the one to climb a tall tree overlooking the other trees in order to provide direction for those with limited vision below. This type of thinking allows one to rise above stand-alone functions and see the system of relationships that connects the individual operations. This is the most effective type of systems thinking; perceiving the "big picture".

Operational thinking: Operational thinking is concerned with causality, looking at relationships or the structure in order to determine the influences of variables on one another. This thinking recognises that in a typical system, there is a web of interdependent relationships.

Closed-loop thinking: This thinking assists in identifying the effects of feedback, that the effect of a cause can influence the cause to change its state. Closed-loop thinking advocates that causes are not to be rigidly prioritised. The level of influences may change as the effects are being observed.

Systems thinking is the application of a certain set of ideas in attempting to understand complexity (Maani and Maharaj, 2004). It acknowledges that a variable can be the cause of one, and effect of another (circular causation); it provides a unique perspective of how pieces of wholes interrelate and how the whole fits into the larger context (Haskins, 2011). It is furthermore the understanding that complex situations are composed of various systems (BKCASE Editorial Board, 2014). Systems thinking requires constant assessing and appreciation of the context of the system of interest to ensure that it is appropriate to the matter being laboured on (Haskins, 2011).

2.3.5 Complex systems

Complex Systems theory is relevant to this thesis because according to ISO 55000 (2014) "An organisation's asset management system is likely to be complex and continually evolving". When discussing the challenges to AM, the IAM (2015) states that: "Assets and systems are complex and often interdependent (making it difficult to draw boundary diagrams and failures often cascade)". ISO 55000 (2014) also states that asset information systems in particular can be extremely big and complex.

The definition of complex systems given by Ladyman *et al.* (2013) is: "an ensemble of many elements which are interacting in a disordered way, resulting in robust organisation and memory". They explain further that complex systems are fundamentally complicated, almost never entirely deterministic, susceptible to unanticipated outcomes and that models of complex systems are also complex (Ladyman *et al.*, 2013). Complex system characteristics according to Ladyman *et al.* (2013) are:

Non-linearity: Any two solutions to equations that describe a system cannot be multiplied by a common factor to obtain another solution that is in proportion and the superposition principle does not apply. Small initial inferences make for radical differences at the end state when modelling. Complex systems also often involve chaos due to non-linearity, but order arises from the disorder of the elements.

Feedback: Element A's interaction with element B depends on element B's interaction with element A at a point in time prior to the current interaction.

Spontaneous order: Complex systems are not totally random, but also not entirely ordered. States and processes may be relative and rely purely on the observers' viewpoint.

Robustness and lack of central control: Robustness is not expressed here as an ability to correct errors, but rather the ability to "maintain direction" despite noise in the system. It can be compared to a pack of migrating animals who, irrespective of the individual disturbances within the pack, maintain overall course because they are not subject to central control. A "critical mass" of changing elements must be reached to make the individual changes affect the whole. This characteristic is seen very prominently in failure investigations where a critical failure is caused by just the right combination of smaller events; events that individually would have no effect.

Emergence: The whole is not equal to the sum of the parts in terms of properties and outcomes. Emergence is linked to the principle of downward causation and carries with it the risks associated with reductionism of the system. Emergence is a result of interaction, and the relationship between elemental system parts (BKCASE Editorial Board, 2014). Whole systems behave and have properties that only become evident once the system is placed in various operating environments (BKCASE Editorial Board, 2014). Another explanation is provided by Pennell and Knight (2005) who state that a system's products interact "toward a common purpose which cannot be achieved by any of the products alone or by all of the products without the underlying organisation".

Hierarchical organisation: Elements interact with each other on similar levels as well as levels below and above. This is needed for emergence. However, the order of a hierarchy contradicts the non-linearity and chaos (unpredictability) exhibited by some complex systems, which may lead to false expectations.

Numerosity: Many more than a few individual elements must interact to truly reflect a complex system. These can however not be broken down to be analysed in isolation. Therefore reduction cannot take place and the characteristic of having numerous elements adds to the complexity of understanding the system.

BKCASE Editorial Board (2014) describes two types of complexities: organised and disorganised. Systems with organised complexity are typically structured into a make-up that is meant to be understood, thus responsive to life cycle management and engineering. Disorganised complexity normally originates from a varied complex system that evolved without direct architecture control allowing for complexity creep. Attributes of each are as follows (BKCASE Editorial Board, 2014):

Disorganised complexity: Loosely linked, disorganised and equal elements which exhibit certain standard properties, e.g. volume, temperature or speed. Systems that display disorganised complexity can be described by statistical analysis methods.

Organised complexity: Strongly linked, organised and dissimilar elements which exhibit emergence, e.g. social or economic systems. These systems can not be described effectively by conventional analysis techniques.

According to Haskins (2011) one of the uses of systems engineering is to effectively manage complexity and change, decreasing the risk associated with complex systems. Zexian (2007) affirms this by saying that the main purpose of the study of a complex system is to find the common properties and "general laws of operation and evolution" of the system. BKCASE Editorial Board (2014) states that when studying complex systems, objective and subjective complexity will be encountered. Objective complexity is described as an attribute of complex systems that gives a measure as to which system outcomes can be predicted accurately and with confidence, regardless of the information available on the current state of the system. Subjective complexity is the extent of how simple it is for an onlooker to predict what a system will do next. Subjective complexity is thus closely linked to each individual's understanding and viewpoint. This can be managed by engaging stakeholders regularly and encouraging communication.

Ultimately, complexity relates to the difficulty in understanding system behaviour in order to predict outcomes when making changes in the system (BKCASE Editorial Board, 2014). This perspective on complex systems rationalises the need for systems thinking.

2.3.6 Systems engineering in context

Systems Engineering (SE), as applied in the DOD, is the application of engineering and scientific efforts to (RSA Department of Defence, 2003):

- Transform an operational need into a description of performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test and evaluation.
- Integrate related technical parameters and ensure compatibility of all physical, functional and programme interfaces in a manner that optimises the total system definition and design
- Integrate reliability, availability, maintainability, safety, survivability, human and other factors into the total engineering effort to meet cost, schedule and technical performance objectives.

The SE activities, the system life cycle and ILS interfaces are shown in Figure 2.8. Although SE is used exclusively for describing the armaments acquisition process by RSA Department of Defence (2003), it can be seen that SE carries on throughout the life cycle of the system. According to Haskins

(2011) during the utilisation phase SE "executes performance analysis, interface monitoring, failure analysis, logistics analysis, tracking, and management that is essential to ongoing support of the system".

Systems thinking, complex systems and tailoring form an integral part of the management of weapon systems in the SAN. In DOD literature SE is described as a "problem solving approach to transform complex requirements into a set of system, component and process descriptions to enable the realisation of successful Products and Products Systems, while generating information for decision makers" (RSA Department of Defence, 2016). SE in the acquisition life cycle stage thus shapes the AI that will be provided to, and initially collected by decision-makers in the operational deployment and maintenance life cycle stage. Once a system is established in the operational environment the PSM must tailor the in-service information feedback as required for decision-making.

2.4 Decision making

As described in Section 2.1.4.2 good decision-making is key to realising value from assets (IAM, 2015). Information and knowledge must be applied in the correct decision-making framework (IAM, 2014). From the previous sections it is evident that complexity and multiple competing variables must be taken into account in addition to focusing the research exclusively on understanding the effects of AI on outcomes. Multi-criteria decision-making (MCDM)[3] must thus form part of the framework developed. This section discusses decision-making in general, followed by a review of relevant methods that could be considered for used in this research.

Holsapple and Burstein (2008) argue that each decision taken has a measure of guesswork hidden within. As the decision maker reviews information certain estimations and assumptions are formed. The anticipated result of a decision is however a guess, which becomes increasingly more difficult as complexity increases (Holsapple and Burstein, 2008). Traditional decision-making involves choosing logically from a set of options available; however, strategic decisions are often unstructured and messy (Martin-Gamboa *et al.*, 2017). MCDM arose as an effective decision support tool when dealing with complexity (Martin-Gamboa *et al.*, 2017). According to Xiaohan *et al.* (2017) MCDM "prescribes ways of evaluating, ranking and selecting the most favourate alternative from a set of available ones which are characterised by multiple and usually conflicting criteria". Ishizaka and Nemery (2013) affirm this statement

[3]Multi-criteria decision-making and multi-criteria decision analysis (MCDA) are terms that are commonly interchanged in literature. For consistency MCDM will be used from here onwards

and add that there is typically not one perfect option, somewhere a compromise must be found.

To address this compromise decision-makers can make use of a simple weighted sum approach; however, this assumes linearity of the criteria and alternatives (Ishizaka and Nemery, 2013). This would not be effective if the decision-makers' utility of preference is, for example, increased by a factor of 5 whilst the criteria is only doubled in value. MCDM methods have been developed in support of finding unique solutions that factors in the subjectivity of decision-makers, who are typically experts. Boundary management, simplification, absorption and integration of logical processes and intuition are typical mechanisms required to influence complex situations and achieve a suitable outcome (Martin-Gamboa *et al.*, 2017).

MCDM methods are discussed briefly in the subsections below. Studies by Marttunen *et al.* (2017) and Mardani *et al.* (2015) that focused on MCDM techniques and their applications as found in articles published between 2000 and 2014 indicated that the methods discussed in the next section could also be applied in this research.

2.4.1 Multi-attribute utility theory

Multi-attribute Utility Theory (MAUT) is based on the supposition that each decision-maker attempts to optimise a function which summarises all of their points of view, consciously or sub-consciously (Ishizaka and Nemery, 2013). The decision-maker's preferences are depicted in a utility function, comprising of marginal utility scores or degrees of satisfaction of each criteria, which are aggregated to a global utility, from which the best possible outcome can be calculated (Velasquez and Hester, 2013; Ishizaka and Nemery, 2013). Utilities are the expression of the degree of well-being that an alternative provides; assigning utilities to criteria brings forth alternatives that are comparable on all criteria where they were not previously (Ishizaka and Nemery, 2013). "The appeal of MAUT is that it combines technical, economic, and risk factors into one aggregate utility index. User perception of all of these factors is implied in the evaluation of utilities" (Elmisalami, 2001).

Advantages: Incomparability, especially when comparing qualitative and quantitative information, does not occur as utility scores are always real numbers (Ishizaka and Nemery, 2013). The set-up preference relation is transitive. According to Velasquez and Hester (2013) MAUT can also take uncertainty into account and incorporate preferences at each step of the method.

Disadvantages: Velasquez and Hester (2013) state that this method can be very data intensive, requiring precise and specific weights to each step, without which assumptions could lead to subjective outcomes. Ishizaka and Nemery (2013) concur with the above and add that the construction of the utility function as well as defining its parameters is another fundamental problem that can discredit the outcome if not done properly.

Applications: MAUT is seen as one of the most commonly used MCDM methods and applications found in literature include facility location, risk optimisation, scenario planning, SWOT analysis as well as cognitive maps and group maps (Velasquez and Hester, 2013; Marttunen *et al.*, 2017). CMs are graphical representations of the perception of an individual in terms of key aspects of a system, which includes perceived causal relationships (Marttunen *et al.*, 2017). The intention with a CM is to improve understanding and inform decision-making, similar to the definition of a framework as described in this thesis. GMs are a combination of individual CMs.

2.4.2 Analytic hierarchy process

After the problem is structured, the Analytical Hierarchy Process (AHP) makes use of pairwise comparisons, a relative appreciation, to determine the value of criteria and the appeal of alternatives (Ishizaka and Nemery, 2013; Marttunen *et al.*, 2017). During the pairwise comparison it relies on the judgement of experts to determine the priority of criteria (Velasquez and Hester, 2013). Often the comparisons are done using a 1 to 9 scale, where verbal preferences are translated to a numerical scale. According to Ishizaka and Nemery (2013) the AHP judgement scales allow for a certain measure of fuzziness, which is particularly helpful in difficult comparisons. A comparison matrix is used to collect the comparisons with the number of comparisons required governed by the following formula:

$$\frac{n^2 - n}{2} \tag{2.4.1}$$

Optional additional steps to improve the validity of the results are a consistency check and sensitivity analysis.

Advantages: One of the main advantages is ease of use; weighting coefficients and comparing alternatives is done with relative ease and, although this requires enough data to perform the comparisons, it does not require as much data as MAUT (Velasquez and Hester, 2013). According to Ishizaka and Nemery (2013) it is especially useful when a utility function cannot be constructed by the decision-maker.

Disadvantages: Problems were experienced with interdependence between criteria and alternatives (Velasquez and Hester, 2013). Due to the comparisons inconsistencies in judgement can develop as grading in isolation to identify weaknesses and strengths is not done. Additions of alternatives at the end of the process could also cause rankings to reverse (Velasquez and Hester, 2013).

Applications AHP is another of the most commonly used MCDM methods which is frequently applied in , cognitive maps, group maps and causal frameworks used for describing interactions between society and its environment, which includes driving forces, impacts and responses (Marttunen *et al.*, 2017). Other applications include SWOT analysis, sustainable fishing operations, transport infrastructure planning and strategic scenario planning (Velasquez and Hester, 2013; Marttunen *et al.*, 2017)

2.4.3 Analytic network process

Analytical Network Process (ANP) is a non-linear form of AHP, which is linear and hierarchical (Velasquez and Hester, 2013). AHP operates under the assumption that the criteria are independent, where ANP allows for dependencies to be modelled (Ishizaka and Nemery, 2013). In essence it operates the same as AHP, but ANP structures the problem as a network and a supermatrix is used to calculate priorities based on the Markov chain process (Marttunen *et al.*, 2017; Ishizaka and Nemery, 2013).

Advantages: The advantages are similar to those of AHP, but ANP has the ability to handle interdependence better and can prioritise element clusters or groups (Velasquez and Hester, 2013).

Disadvantages: Besides problems with interdependence the disadvantages are the same as those of AHP (Velasquez and Hester, 2013).

Applications: ANP has been used in project selection, scheduling problems, SWOT analysis as well as similar causal frameworks as AHP (Velasquez and Hester, 2013; Marttunen *et al.*, 2017). According to Mardani *et al.* (2015) ANP was also applied in problems involving the evaluation and ranking of factors in various sectors as well as asset valuation.

2.4.4 Fuzzy set theory

According to Bojadziev and Bojadziev (2007) “there is not a unique system of knowledge called fuzzy logic but a variety of methodologies proposing logical consideration of imperfect and vague knowledge”. At its core fuzzy logic is a theory that allows the solving of problems when dealing with insufficient information (Velasquez and Hester, 2013). Fuzzy logic makes use of fuzzy set theory, which can be used by itself as a MCDM method, or more commonly, in combination with other MCDM methods (Bojadziev and Bojadziev, 2007; Velasquez and Hester, 2013; Marttunen *et al.*, 2017).

Advantages: The advantage of using fuzzy logic is that it allows for imprecise data input (Velasquez and Hester, 2013). This advantage is added to the advantages of any other method in the case of a fuzzy-hybrid method.

Disadvantages: The disadvantage of fuzzy logic is that it can be difficult to develop to a real-world application level, requiring many simulations (Velasquez and Hester, 2013).

Applications: Fuzzy set theory has seen application in cost-benefit analyses, ranking problems as well as risk and resource management (Velasquez and Hester, 2013). Resaei *et al.* (2013) used a quantitative fuzzy AHP (FAHP) model to determine the factors most effective in optimising banks' balance sheets. Chen and Wang (2010) used an FAHP model coupled with a Delphi approach to develop a framework with business element performance indicators and weights to support strategic decision-making in information services firms.

2.4.5 Data envelopment analysis

Data Envelopment Analysis (DEA) is used to score efficiency and aids decision-makers by providing a performance measurement (Ishizaka and Nemery, 2013). It creates a benchmark from which to rate efficiencies with alternatives, but can also be used to calculate the adjustments required to input and output criteria in order to become efficient (Velasquez and Hester, 2013; Ishizaka and Nemery, 2013). The DEA technique uses linear optimisation to calculate the set of weights used to measure relative efficiencies of the alternatives.

Advantages: DEA is able to handle multiple inputs and outputs. Relationships hidden with other methods can also be uncovered (Velasquez and Hester, 2013).

Disadvantages: This method does not work with imprecise data. As it deals with efficiency measurement, it assumes that all input and output data is precise (Velasquez and Hester, 2013).

Applications: DEA is used to measure the efficiency and performance of various private and public organisations (Velasquez and Hester, 2013; Ishizaka and Nemery, 2013). However, when applied with other MCDM methods, it has also been used in ranking problems (Mardani *et al.*, 2015).

2.4.6 Technique for order of preference by similarity to ideal solution

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) identifies, or ranks, alternatives according to what is geometrically the closest to the ideal solution and furthest away from the negative to the ideal solution (Velasquez and Hester, 2013). Criteria must be weighted and the performance of alternatives in each criteria must be known. The performances are then normalised, weighted accordingly and the distances to the ideal and anti-ideal point are calculated, typically using Euclidean distance (Ishizaka and Nemery, 2013). The preferred alternative is the selected based on the closeness coefficient.

Advantages: The main advantage of TOPSIS is its simplicity and ease of use, it is programmable and the number of steps in the process remain the same regardless of problem size (Velasquez and Hester, 2013). The output of this method is easily understood by the user and minimal inputs are required (Ishizaka and Nemery, 2013).

Disadvantages: The user inputs required for the criteria weights are subjective, but the performances of the alternative in each criteria field need to be precise to yield credible results (Ishizaka and Nemery, 2013). TOPSIS methods based on Euclidean distances can yield different results than if Manhattan distances were used and it does not take the correlation of attributes into consideration (Velasquez and Hester, 2013; Ishizaka and Nemery, 2013). According to Ishizaka and Nemery (2013) TOPSIS can sometimes provide illogical results.

Applications: TOPSIS has been applied in CMs, SWOT analysis, scenario planning, ranking problems and causal frameworks in a variety of sectors including engineering, manufacturing, supply chain, logistics and business management (Velasquez and Hester, 2013; Marttunen *et al.*, 2017; Mardani *et al.*, 2015). As with DEA, although a pure TOPSIS approach is probably not viable for use in this thesis there are examples of hybrid approaches that still require the TOPSIS MCDM method to be included as an option that can be incorporated. For instance, Sekhar *et al.* (2015) made use of a hybrid Delphi-AHP-TOPSIS methodology to develop a framework for critical indicators of intellectual capital, which included the inter-relationships between indicators.

2.4.7 Preference ranking organisation method for enriched evaluation

Preference Ranking Organisation Method for Enriched Evaluation (PROMETHEE) provides decision-makers with a ranking of alternatives by calculating preference flows based on pairwise comparisons (Marttunen *et al.*, 2017; Ishizaka and Nemery, 2013). Several iterations are required and various levels of rankings exist. PROMETHEE I ranking is based on positive and negative preference flows and provides partial ranking of alternatives. PROMETHEE II ranking allows for complete ranking by being based on net flows only, avoiding incomparability as sometimes experienced by positive vs negative scores in PROMETHEE I (Velasquez and Hester, 2013; Ishizaka and Nemery, 2013).

Advantages: Advantages of PROMETHEE include its ease of use and not requiring the criteria to be proportionate (Velasquez and Hester, 2013).

Disadvantages: A disadvantage is that there is no clear method defined by which to assign weights nor the assignment of required values for the preference and indifference thresholds (Velasquez and Hester, 2013; Ishizaka and Nemery, 2013).

Applications: The PROMETHEE applications found in literature include scenario planning, SWOT analysis and ranking problems in sectors such as project management, banking, manufacturing, business and finance (Velasquez and Hester, 2013; Ishizaka and Nemery, 2013). Hybrid MCDM approaches involving PROMETHEE include trade-off analysis, facility location and choice problems (Mardani *et al.*, 2015)

2.4.8 ELECTRE

Elimination Et Choix Traduisant la Realité (Elimination and Choice Expressing Reality – ELECTRE) is a family of MCDM methods developed over time to solve choice, ranking, sorting and elicitation problems (Ishizaka and Nemery, 2013). It is essentially an outranking method using concordance analysis (Velasquez and Hester, 2013).

Advantages: The ELECTRE methods avoid any normalisation process or compensation, which could distort the original data (Ishizaka and Nemery, 2013). Velasquez and Hester (2013) furthermore state that it takes into account vagueness and uncertainty.

Disadvantages: A major disadvantage is that it can be hard to explain the process and its outcomes to a layman; furthermore, the lowest performance in certain criteria is often not displayed (Velasquez and Hester, 2013).

Applications: As this is a family of methods its use is widespread. However, common applications are in causal frameworks, strategic assumptions surfacing and testing as well as strategic options development and analysis (Marttunen *et al.*, 2017). The ELECTRE family of methods are commonly found in hybrid MCDM applications (Mardani *et al.*, 2015). According to Ishizaka and Nemery (2013) ELECTRE methods can be applied when problems have more than two criteria and meet any one of the following conditions:

1. The criteria's performances are expressed in different units and developing a common scale is not desired;
2. A compensation effect is not permitted by the problem;
3. There is a need for preference and indifference thresholds from the decision-maker;
4. The alternatives are evaluated on a weak interval scale, or a scale representing an order where it is difficult to compare differences.

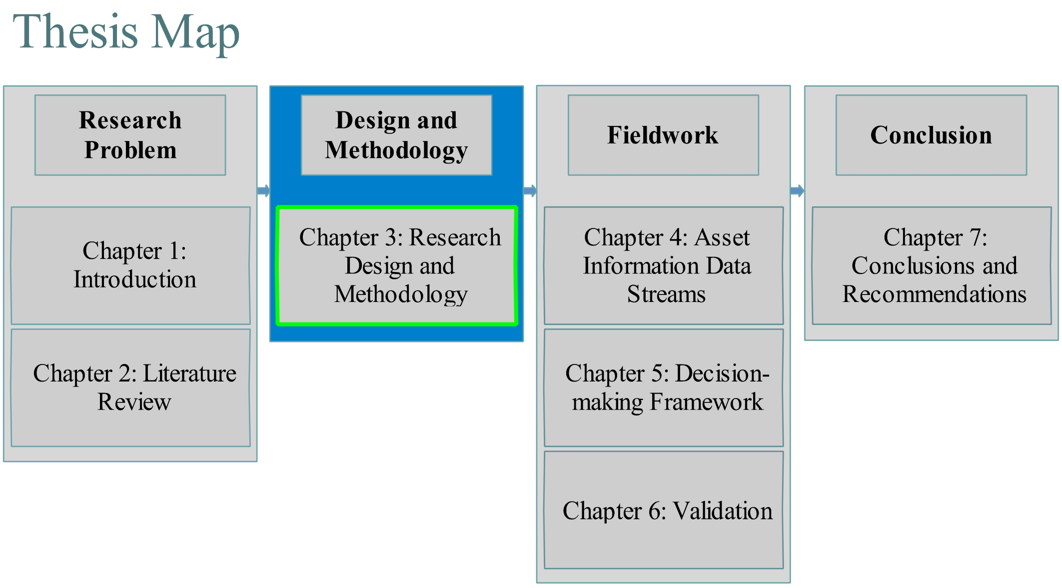
2.5 Chapter summary

In conclusion, Chapter 2 outlines the origins, definition, fundamentals and elements of an AM system. A general overview of maritime security and the role of the SAN is provided before the application of AM, and specifically AI, in the SAN is reviewed. Arising therefrom, SE theory as applicable to the logistic management and life cycle stages of assets in the SAN is studied. The final section of the chapter is dedicated to decision-making that is applicable to AM in the SAN as well as the methodology of solving the research problem.

This chapter addressed the first sub-objective of this study with the aim of providing the reader with an overview of relevant literature regarding the environment and context of AM in the SAN as well as AM, decision-making and SE in general. The next chapter uses the literature review as a foundation to construct a well-grounded methodology in order to solve the problem statement.

Chapter 3

Research design and methodology



The aim of this chapter is provide a thorough review of the research methods used to reach the conclusions of this thesis. It will outline the general research approach, followed by a detailed description of the research design and research methodology. Ethical considerations will be discussed as part of the data collection chapter.

3.1 Research approach

"Different kinds of research approaches produce different kinds of knowledge about the phenomenon under study" (Blaxter *et al.*, 2006). Blaxter *et al.*

(2006) continue by stating that the way general philosophical questions are applied to research underpins the research designs and methodologies. Creswell (2013) similarly states that the decisions involved in deciding on a method to collect, analyse and interpret data are driven by the philosophical assumptions of the researcher, the research strategies chosen and the specific methods used to execute the strategies. The philosophical assumptions, or worldviews, of the researcher are described as the guiding beliefs that lead to adopting an approach in research (Creswell, 2013).

Creswell (2013) suggests that this philosophical worldview be stated clearly to aid the reader in understanding why a specific approach was chosen. Accordingly, the philosophical base of this research is that of pragmatic worldview. Pragmatism is concerned with finding practical solutions to problems, focusing on the research problem and making use of any applicable method to understand the problem (Creswell, 2013). A pragmatic worldview is well suited for use with the mixed method approach according to Creswell (2013) as it provides the freedom to use multiple methods, assumptions, forms of data collection and analysis techniques.

3.2 Research design

The research design is part of the strategy that is used to undertake the research, the foundation upon which the research methodologies are based. According to Creswell (2013) it can either be qualitative research, quantitative research or mixed method research. Blaxter *et al.* (2006) and Creswell (2013) describe the qualitative research approach with, amongst others, the following characteristics: subjective, understanding from individual's frame of reference, holistic and assuming of a dynamic reality. Qualitative research is normally undertaken when the research problems are not fully developed in previous research and need to be explored and described (Creswell, 2013). Quantitative research is described as outcome-orientated, seeking facts or causes, examining relationships of variables, but may contain non-experimental methods such as surveys (Creswell, 2013; Blaxter *et al.*, 2006). The mixed method research approach is described by Creswell (2013) as:

> "an approach to inquiry involving collecting both quantitative and qualitative data, integrating the two forms of data, and using distinct designs that may involve philosophical assumptions and theoretical frameworks. The core assumption of this form of inquiry is that the combination of qualitative and quantitative approaches provides a more complete understanding of a research problem than either approach alone"

In order to answer the research questions an exploratory sequential mixed method design is adopted. This design sees qualitative data collected and analysed, before commencing with the second phase, which is more quantitatively orientated. The first and second research questions are open-ended questions that require exploration of the field. After this fieldwork these findings are discussed, which marks the conclusion of the qualitative phase. To answer the third research question a quantitative approach is used, where the data collected in the first phase is used as a basis for a pre-determined approach to the second round of data collection and analysis. After construction of the SANAIDMF, validation follows, where face validation and user assessment are used to validate the decision making framework[1].

The second phase of the research is seen as quantitative although both quantitative and qualitative methods are used. The exploration instrument is qualitative, seeking subjective expert opinions. However the data analysis and the output are quantitative, resulting in the quantitative component of the phase being more distinct.

3.3 Research methodology

Two phases are used to answer the three secondary research questions, and ultimately the primary research question. The first phase starts with a survey-based questionnaire to collect data. This answers the first and second research questions, which are:

- What critical decisions affecting operational availability of systems in the SAN are taken that require AI as input?
- What are the AI data streams that support critical decision-making affecting operational availability in the SAN?

In phase two the third research question, determining how to construct a framework to understand the impact of AI on operational availability, is answered by means of decision support modelling. This involves collecting data with a questionnaire based on the outcome of phase one and hybrid AHP-MAUT principles. The data collected is then analysed and a decision support framework constructed. Finally, the model is validated by means of face validation and user assessment. Table 3.1 summarises the methodology followed.

The research methodology section is further divided into three interrelated sections: participant identification, data collection and data analysis. These are explained in the following subsections.

[1]Validation is discussed in detail in chapter 6

Phase	Approach	Process	Method	Ch.
1.	Qualitative	Data collection	Survey-based questionnaire	4.
2.	Qualitative	Data collection	Questionnaire based on AHP-MAUT	5
	Quantitative	Data analysis	Decision support framework	5
	Qualitative	Validation	Face Validation and User Assessment	6

Table 3.1: Research methodology summary

3.3.1 Participant identification

During this mixed method inquiry is it required to obtain information from a larger number of user experts before obtaining detailed viewpoints about the concept from a smaller group of subject matter experts. Creswell (2013) states that in a mixed method design it is acceptable to survey a larger number of individuals, following up with fewer individuals for a better understanding. The second phase of the inquiry builds on the outcome of first phase, but the questionnaire is more time-consuming. Limited availability of time is thus one of the reasons why the number of participants for the second phase is reduced to only a few experts.

According to Creswell (2013) the idea behind a qualitative study is for the researcher to purposefully select participants who will best assist in understanding the research problem. Hofstee (2015) affirms this by explaining that questionnaires should be sent to people who are presumed to have the required information. For this study the participants must have a working knowledge of the topic being researched or be an expert in the field.

For the first phase of this research the participant selection is based on first hand experience and knowledge of the topic. As detailed in Section 2.2.2 a systems approach is followed by the DOD with Product System Managers (PSMs) managing its assets. The PSM ensures that the required levels of availability of mission capable combat systems are maintained. Prospective participant identification for the first phase is based on experience in the SAN; current or previous PSMs are included in this group. Individuals who have experience in positions directly senior to PSMs are also included. The primary researcher is a serving senior officer in the SAN and the prospective participants are colleagues of the primary researcher. Personal knowledge of the management group in the SAN is used by the primary researcher when applying the above criteria to participant selection. The prospective participants identified are all employees of the SAN (DOD), with the contact details of participants available to the primary researcher, being an employee of the same institution as the participants.

The second phase of this research again requires participants. However, as mentioned above these participants must be subject matter experts. Thus, due to availability and time constraints, fewer prospective participants are identified. A questionnaire based on AHP-MAUT principles is distributed to the participants. This questionnaire aims to provide a dual outcome, firstly quantifying the link between the AI elements identified in the first phase and the operational availability of systems. Secondly, it aims to provide the baseline values for the SANAIDMF. The participants in this case are chosen based on background and experience in the field of AM and AM in the SAN. The most senior officials possible are used, creating a divide between the user group and the subject matter expert group. Again, only prospective participants in the employ of the SAN (DOD) are identified and thus the same principles as in the first phase apply to selecting and contacting prospective participants.

Encoded information profiles of the participants are listed in tables in Chapters 4 and 5. These participant information profiles provide the professional background and experience of the participants indicating the factors which makes them suitable experts for this study. The tables are thus intended to add to the credibility of the questionnaire results. The identity of the participants remains confidential as stipulated in the ethics policy of the University of Stellenbosch. Random participant codes are used and the consent form in Appendix B and D can be consulted for more details regarding confidentiality and the protection of information.

3.3.2 Data collection

Secondary data sources are used for the literature study, and throughout the rest of the thesis, to provide background and context to the research problem. Primary data collection is carried out using questionnaires, which is described by Welman *et al.* (2005) as an appropriate instrument to obtain opinions, beliefs or convictions about any topic. Structured face-to-face interviews could also be used, but were not considered because of their time-consuming nature. According to Blaxter *et al.* (2006) postal and email questionnaires typically have a low response rate as well as possibly deficient answers as there is no one to clarify queries. Structured face-to-face interviews on the other hand have a better response rate and having the researcher present to answer questions leads to answers that are more reliable and credible (Blaxter *et al.*, 2006).

Two sequential data collection phases are carried out. In both phases of this research appointments were made with each prospective participant and after agreeing to take part in the research the questionnaire was explained by the researcher. This appointment provides the opportunity for the participant to ask clarifying questions and produces results relevant to the research. By ending the contact and leaving the participant to complete the questionnaire in his or her own time it is less time-consuming for both the researcher and the participant. However, there were still some response rate issues experienced as some prospective participants indicated their willingness to participate, but never completed the questionnaire. Thus, despite attempts to blend questionnaires with the advantages of face-to-face interviews, not all of the disadvantages could be eliminated. Scheduled contact sessions via appointments driven by the researcher did, however, make the data collection process more effective.

The first phase questionnaire consists of two exploratory open-ended questions directly related to the first and second research questions. Participants are given background information and details of the study, and asked to provide their expert opinion on the subject. After receiving the questionnaires back from the researchers the data is combined on an Excel spreadsheet. In accordance with a pull strategy the focal point of the questionnaire must be on the decisions taken in the SAN that have a noteworthy effect on operational availability. That was thus the subject of the first questionnaire, where the information required to take such decisions is asked for as elements of the decisions. Capturing the results on a spreadsheet allows the researcher to transpose the data, making the information requirements the subject and the decisions the hangers-on. This shift of focus is required to set up the second phase questionnaire.

In the second phase a questionnaire is set up after a preliminary decision making framework is constructed. The first step of this questionnaire asks of participants for a series of personal preference pairwise comparisons with respect to criteria in order to set up the utility function. In the second step participants are asked to provide their expert opinion on the attributes of the alternatives identified in the first phase. The data collected in the second questionnaire forms the baseline data for the SANAIDMF.

Approval for the data collection was granted by the Stellenbosch University's Humanities Department ethical committee. See Appendix A for approval letter.

3.3.3 Data analysis

"Analysis is about the search for explanation and understanding, in the course of which concepts and theories will likely be advanced, considered and developed" (Blaxter *et al.*, 2006).

The first phase data analysis is carried out with qualitative data analysis methods and described in the following series of steps:

Step 1 A report is made regarding the participant group size, response rate and participant information. The participant information pertains to what qualifies them as experts who are used to complete the questionnaires.

Step 2 Organising and preparing data. A form of coding is used, where coding is described by Blaxter *et al.* (2006) as a process by which data items or groups are assigned codes to reduce the quantity and to standardise data. Coding in this instance does not assign an arbitrary number, but rather assigns individual elements to a group with a group name representative of the elements assigned to it. Coding is done within an Excel spreadsheet, without the use of specialised software. The total number of occurrences that an element from the group is identified in the questionnaires is also reported on.

Step 3 Further reduction of the raw data is done by grouping AI elements under a standard term. The reduction and summarising of data is carried out so that it can be used optimally in the second phase.

Second phase data analysis starts with transposing the data, as explained in Section 3.3.2 above, to construct the preliminary framework and set up the second phase questionnaire. After the receiving the questionnaires back the following steps are carried out for quantitative data analysis:

Step 1 As in the first phase, the participant group size, response rate and participant information are reported on. With a small sample size the response bias is not commented on.

Step 2 The data-sets received back are combined into a single data-set with mean values. The standard deviation per individual AI element is commented on.

Step 3 The mean values are inserted into the preliminary framework from where the AHP-MAUT based algorithms are used to analyse and rank the data.

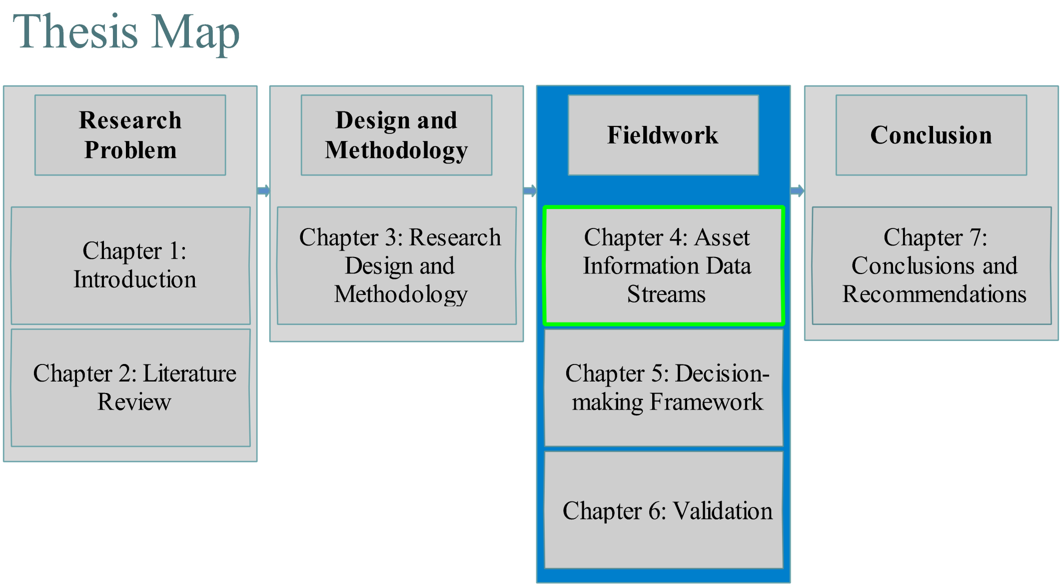
3.4 Chapter conclusion

This chapter addressed the second sub-objective: construct a well-grounded research methodology. Research approaches, design and methodology relevant to this study are discussed. The research methodology, with details of data collection, analysis, participant selection and ethical clearance requirements, is constructed based on considerations of the research problem and the research questions. A mixed method approach with a qualitative first phase and a quantitative second phase is identified.

The next chapter identifies AI-based decisions and data streams required to support AI based decision-making. The aim with the following chapter is to address the third and fourth sub-objectives and answer the first and second secondary research questions.

Chapter 4

Asset information data streams



The objective of this chapter is to perform the qualitative phase of the research. The chapter begins with an overview of the first round data collection process after which the outcome of the survey is presented. A section is dedicated to the findings and discussions of the first phase research results, which is used to highlight AI data streams critical to decision-making in the SAN. In the first round data collection the third and fourth research sub-objectives are addressed. The outcome of the research also answers the first and second secondary research questions.

4.1 First round data collection

One of the AM fundamentals as described by ISO 55000 (2014) is value. AM is concerned with producing value in an organisation by using assets, which requires all asset components in an organisation to form part of a value chain. AI and data form part of this value chain, as does data accountability. Data can be gathered on almost every aspect of assets, but that is not to say it should be. Too much data can be superfluous and only serves to add unnecessary complexity to its management. Overwhelming decision-makers with too much data to mine is in all likelihood not effective. On the other hand, not having sufficient information or obsolete information is also equally problematic. AI together with the correct measure of pragmatic quality is required.

The research approach, of first identifying significant AI-based decisions affecting the operational availability of the SAN's systems, seeks to identify frequent data and AI needs following a pull strategy. This top-down approach of first establishing the needs also validates the AI elements identified for use in phase two of the study. The aim of this part of the research is to establish a value chain between AI and operational availability, where meeting the required operational availability leads to the SA Navy being able to meet its core output requirements. The effects of specific AI elements on operational availability are researched in phase two of the study.

4.1.1 Data collection process

The method chosen for identifying significant AI-based decisions in the SAN is a survey-based questionnaire. This is sent to employees of the SAN presumed to have the relevant knowledge or experience to elicit the required information. Prospective participant selection is done as detailed in Section 3.3.1.

After the selection of prospective participants a survey-based questionnaire and a consent form (Appendix B) is handed to the participants during a scheduled meeting. The study is explained by the primary researcher and the prospective participants have the option to agree to partake in the study, or not. A period of two weeks is given to complete the questionnaire, after which another meeting is scheduled between each individual participant and the primary researcher to collect the completed questionnaire. Particulars of the participants are collected during the survey, but encoded with a random number as per the consent form. The reason for collecting this information is to add credibility to the findings by listing the professional background of participants.

4.1.2 Questionnaire outcome

The questionnaire asks experts their opinion as to which decisions have a noteworthy effect on the availability of systems in the SA Navy, and what information is required to make such decisions. Initially ten prospective participants were identified, all of whom agreed to partake in the study. However, of the ten participants who initially agreed, only seven completed the survey. Out of the seven who completed the survey six answered the survey from their own experience. one participant provided no decisions and used extracts from SAN literature to list information requirements. The ‘textbook’ answer to the survey is disregarded as it does not reveal the real data needs for decision-making, but rather provides the viewpoint that all AI is equally important. Therefore only six completed surveys are included in the study.

Details of the participants, relevant to the validity of the answers, are displayed in Table 4.1.

Table 4.1: Encoded participant information for the first round data collection

Participant code	**Current position and responsibilities**	**Experience in this field**
Participant 1	**System manager diving systems and equipment** Manages diving equipment for the SA Navy, including maintenance and repairs	9 years
Participant 2	**Logistics manager acquisition project** ILS management of the product system during the acquisition phase with emphasis on ILS deliverables	10 years
Participant 3	**System manager combat support ships** Manages the integration of logistic requirements, budget, obsolescence and disposal of Combat Support Ships	17 years
Participant 4	**Manager system support** Budgeting and management activities for the rejuvenation of product systems, contracting of private industry, integration of new acquisitions as well as disposal of obsolete materiel[1]	12 years
Participant 5	**ILS manager naval engineering services** Provide a logistic engineering service to the SA Navy which include developing logistic element deliverables and configuration control of all systems and equipment of the SA Navy	32 years

[1]Materiel (often spelled matériel in US English) refers to all items used or needed in any business, industry or operation such as hardware, firmware, software and bio ware (other than personnel) i.e. military material and equipment (South African Navy, 2008).

Table 4.1: Encoded participant information for the first round data collection

Participant code	Current position and responsibilities	Experience in this field
Participant 6	**System manager submarines** Providing an equipment level submarine product system to the SA Navy	18 years

4.2 First round data analysis

AI is the enabler when making decisions to effect change in, or maintain, the operational availability of systems. Meeting the required operational availability targets leads to the SAN being able to meet its core outputs. The critical decisions affecting operational availability are established based on the outcome of the questionnaires. These decisions will not be explored further as they only serve to establish the value chain between AI and operational availability. Later in the study the focus is on AI elements as the enabler to decision-making and the decisions identified will only be used to provide context for decision-making.

The outcome of the questionnaire is presented before discussing the findings and contextualisation with specific reference to how the information is used in the SAN. The results of the first round data collection is used as input for the second questionnaire, which aims to elicit the value of each of the data streams.

In the results it is observed that specific decisions as well as families of decisions were identified by the various participants. For simplification and standardisation the individual decisions are organised together with the families of decisions listed, where possible. Before coding there were 31 decisions and decision families identified by the participants. After coding the decisions and decision families amounts to 16, which will be referred to simply as decisions from here on. The results, after grouping the critical decisions, are shown in tabular format in table 4.2.

Table 4.2: Phase one questionnaire results

Decision number	Survey outcome: Typical decisions that are made in the SAN which affect the availability of systems	Number of occurrences
1	Budgetary decisions	4
2	Re-supply of spares related decisions	4

Table 4.2: Phase one questionnaire results

Decision number	**Survey outcome: Typical decisions that are made in the SAN which affect the availability of systems**	**Number of occurrences**
3	Obsolescence related decisions	4
4	Unscheduled repair related decisions	3
5	Scheduled maintenance related decisions	3
6	Level of ambition decisions[2]	2
7	Re-supply of mission related products decsions	2
8	Movement of maintenance periods due to operational requirements related decisions	1
9	Movement of key maintenance personnel due to operational requirements related decisions	1
10	Cannibalising[3] vessels to meet operational requirements related decisions	1
11	Changing the roles of vessels beyond designed roles as well as equipment life extension related decisions	1
12	Engineering change related decisions	1
13	Spares refurbishment related decisions	1
14	New mission related equipment procurement decisions	1
15	Execution of planned activities related decisions (daily management)	1
16	Additional in-house maintenance support and training related decisions	1

Coupled to the question of which are the critical decisions for availability of systems in the SAN is the question of what information is needed to make such decisions. The participants are asked to stipulate what information is required, in their expert opinion, to make the stated decisions.

Similar to the coding of decisions, there are some groupings that can be done to simplify the results. Although the AI requirements listed are specifically identified by the experts, in some instances the participants used different

[2]Level of ambition is a term used in the South African Defence Review 2015 that refers to what the Government expects the DOD to do. Level of ambition is offset against the available budget, where the budget must be adjusted upwards or the level of ambition lowered. (Mapisa-Nqakula, 2015)

[3]Cannibalising is the process where parts are taken from one vessel in order to repair another vessel.

terms to describe the same AI requirement. In those cases a single term between those listed is chosen to represent the two or more AI requirements, ensuring that the grouped term will yield the same information output. Grouping under a standardised term is done in order to condense the inputs for the second questionnaire and ultimately the decision-making framework. Grouping also allows an AI element requirement to be evaluated once and not frustrate participants and users with similar terms. In both the second questionnaire as well as the SANAIDMF, metadata are provided with the AI elements to retain its origins and provide context. The metadata are; how many times the AI element was required, and in which decisions is the AI element required.

When grouping the critical decisions, the related AI element requirements are moved with each decision. The results of the questionnaire depicting the ungrouped AI requirements listed under the grouped decisions are shown in Appendix C. Grouping of the AI elements as explained above is only visible in the second questionnaire. The stepwise execution of grouping, first decisions and then AI elements, is performed to show data analysis progression and add to the validity of results. Before grouping 102 AI elements are listed, after grouping the AI elements total 66.

4.3 First phase results

Literature on AI shows that there are two types of data relating to product systems: Baseline data, which includes technical publications and design data, and in-service feedback data (S5000, 2016; S1000, 2012; South African Navy, 2008; South African Navy, 2014). S5000 (2016) explains that in-service data is used for operational and maintenance performance analysis with the aim of increasing availability and effectiveness as well as improving global support and product life cycle cost. “Operational and maintenance feedback enables the implementation of efficient and powerful system improvements as well as valuable support in the usage of products with respect to availability, affordability and maintainability” (S5000, 2016).

The results of the questionnaire are representative of the AI element[4] categories found in literature. The AI elements tabled can be categorised in one of the two data types mentioned above, with numerous elements per data type. The various AI categories and considerations as listed in Section 2.1.4.4 are also well represented in the results. There are, however, other AI elements not tabled in the research findings, which could be included if required for different decisions or by different decision-makers. This speaks to the fluidity of the foundations of this decision-making framework. In the end, the survey

[4]For the purpose of this research and for simplification the information requirements identified in the questionnaires will all be called AI elements.

result representativity of the standards and specifications found in literature adds to the validity of the research.

S1000 (2012) states that the smallest self-contained information unit is called a data module. Various examples of data modules, which cannot be broken down further, are listed in the results. There are also many terms that are not data modules but have a structure of data modules of their own, which collectively provide the information as described by the term. This indicates a hierarchical organisation within the data-set tabled, which is a characteristic of complex systems (see Section 2.3.5). This hierarchical structure brings out the phenomenon of emergence, which is also a characteristic of complex systems. Together the information empowers decision-makers more than when individual AI elements are consulted in isolation. The emergent properties of AI will, however, not be explored further as they fall outside the scope of this study.

Other complex system characteristics displayed amongst the AI elements tabled are numerosity and feedback. The AI element set thus constitutes a complex system which displays organised complexity, which according to BKCASE Editorial Board (2014) cannot effectively be described by conventional statistical analysis techniques. It is, however, typically structured into a make-up that is meant to be understood and is responsive to life cycle management and engineering. This serves as the reasoning why a dynamic framework which betters understanding is developed instead of a prescriptive model as a decision support system.

In developing the framework, some AI elements are grouped as explained in Section 4.2. Some elements can also be broken down into data modules. This is however not done in this study as the collective represents what is required by the decision-maker. Breaking it down into data modules adds complexity and could lead to confusion when some of the data modules of AI elements are listed on their own as AI elements required. Instances where this could happen is where in-service feedback data needs to be compared to baseline data to determine performance. To that effect some AI elements must be contextualised and their make-up discussed as it is applied by the SAN. These AI elements are Logistic Support Analysis, Operation Support Base Line and Job-card feedback.

Logistic Support Analysis (LSA) is described by US Department of Defense (1983) and S3000 (2014) as a methodical analysis dealing with all, or nearly all, supportability objectives providing preplanning of ILS aspects which should result in a reduction of cost and increased maintenance efficiency. This process is executed during the design or acquisition life cycle phase of a product with two general objectives of firstly influencing the design in such a way that the most effective support concept is implemented, and secondly predefining the logistic support requirements (S3000, 2014). The level of detail of the LSA should be tailored to each product, bearing in mind the product's intended use during in-service operations (S3000 2014; South African Navy 2008). The outcome of the LSA is stored in a database called the Logistic Support Analysis Records (LSAR).

In SAN policies, as well as other literature sources on AM, tailoring plays an important role. The South African Navy (2008) defines tailoring as "the act of identifying the particular ILS requirements that will have the greatest effect on improving the supportability of the equipment, their scope and depth of application and the LSAR requirements that will have the greatest effect on improving the supportability of the equipment through life". The SAN tailored various military ILS related standards to suit its requirements by reducing data outputs to only those which are relevant, whilst maintaining the inherent principles (South African Navy, 2014). To bring LSA in line with Systems Engineering the term LSA is used in the SA Navy under the heading of Logistic Engineering, with the following minimum subsections: logistic analysis candidate selection, front-end analysis as well as detail task and support requirement analysis. The South African Navy (2014) describes in detail how RAM, FMECA, RCM and operator interface control analyses results in detailed maintenance tasks, support element requirements, operations tasks and designed performance parameters.

LSA outputs are, however, not limited to the above in the SAN, but tailored specifically for the product system being analysed. Because this study does not focus on a specific product system in the SAN the details of which specific AI elements are captured in the LSAR of a product system are not important for this study. However, that there is an LSAR, with LSA data uniquely tailored for each product system based on its intended operation, is critical. It is important for system managers in the SAN to understand what brought about the Product System Management System (PSMS) and Product System Management Plan (PSMP). These are used to adequately manage the ILS process of a product system as well as ensure materiel readiness of the product system at the lowest possible cost (South African Navy, 2008). Both the PSMS and PSMP are developed gradually from the requirements definition phase to eventually be presented as the OSBL at the start of the operational deployment and maintenance phase, making use, inter alia, of LSA data. LSA data is thus important for decision-making in the operational deployment and maintenance life cycle phase as it presents the system manager with the information used to set up various management systems and plans in order to achieve the designed operational availability. These theoretical values are then compared to those observed in practice. If the observed values are not acceptable in comparison with the designed values changes must be made, which invariable requires decision-making.

LSA data will not be dissected to individual AI elements or data modules, but used as an individual AI element in this study. Some of the other AI elements listed in the questionnaires might form part of LSA data; in such cases those elements will be considered as stand-alone from the LSA data for the reasoning provided above. It must be noted that both LSA data and LSAR are used by the experts who completed the questionnaires. However, as both terms provide reference to the same entity only LSA data will be referred to from this point onwards in this thesis.

The definition and contents of an OSBL are discussed in detail in Sections 2.2.2 and 2.2.3. In addition to that, it must be noted that LSA data forms the nucleus of the OSBL. Both are of cardinal importance for the System Manager during the operational support and maintenance life cycle phase. Similar to LSA data, OSBL provides a reference point against which the physical and logistic support design of a product system can be measured to ensure design integrity throughout the system's operational life (South African Navy, 2008). The OSBL serves as the demarcation between the acquisition phase and point of departure for the Operational Phase (RMSS, 2007). The OSBL is only qualified once it is demonstrated that the design and newly created logistic support, as captured in the OSBL, conforms to the historically specified requirements. The OSBL must be successfully established in an integrated manner at the beginning of the operational phase (South African Navy, 2008).

As with LSA data, the term 'qualified OSBL' will not be broken down into its subcomponents, but used as an AI element on its own. It is the collective set of uniquely tailored data items forming the OSBL that enables the system manager to make a decision where it was indicated that a qualified OSBL is an information requirement. OSBL and LSA data form part of the baseline data group.

S5000 (2016) states that a new system being introduced typically requires close observation to make sure that the system capabilities are exploited optimally. This requires processes to be in place to manage the required information feedback and data flow to ultimately facilitate decisions and recommendations (S5000, 2016). Job-card feedback is an example of a process put in place to facilitate data feedback. It is also a term that entails different information sub-elements, depending on the details required by the specific job-card. According to S5000 (2016), when a maintenance organisation performs maintenance on a product, whether it is corrective or preventive maintenance, maintenance data must be collected. This data is analysed and used to improve maintenance practices as well as improve reliability, safety and availability of the product (S5000, 2016).

A preventive or scheduled maintenance card's feedback will typically centre around the accuracy of the existing information on the card, for planning purposes (S5000, 2016). For example, the card states that it will take an artisan one hour to complete the task, where in fact it takes two hours to complete the task. If the time difference is found to not be an once-off anomaly, the standard information on the card will be updated necessitating replanning, but future job scheduling will be more accurate. The typical information expected on preventive maintenance job-card feedback is (Birkenstock, 2014; S5000, 2016):

1. Measured task duration;
2. Measured working time of personnel;
3. Task date and time;
4. Product's operational metrics;
5. Discrepancies with regards to skill, material and special tool requirements as listed on the Standard Maintenance Task Card.

Corrective maintenance, on the other hand, requires more information on the job-card feedback report. This includes (Birkenstock, 2014;S5000, 2016):

1. Failure data;
    a) Failure source
    b) Failure description
    c) Failure date and time
    d) Product usage information when failure occurred
2. Reference to a standard maintenance task used to correct failure (if any);
3. Measured task duration and measured working time duration;
4. Information pertaining to materials used and components exchanged such as part and serial numbers;
5. Product's operational metrics.

In-service feedback, such as the information found on job-card feedback, enables system managers to analyse operational and maintenance performance with the overall aim of increasing product availability and decreasing life cycle cost S5000 (2016).

In addition to feedback of data for maintenance analysis S5000 (2016) recommends in-service data feedback for RAM analysis, safety analysis, supply support, life cycle cost (LCC) considerations, warranty analysis, obsolescence management, integrated fleet management, configuration management and support service contracts. All of the categories recommended are represented to a greater or lesser extent in the AI elements tabled. This increases confidence that the top-down data collection method is indeed providing the intended outcome of AI elements to be used in the SANAIDMF.

Other than the AI elements discussed above the AI elements listed in Tables C.1 to C.4 are specific, either at its most basic form or non-complex AI elements with sub-elements relating to a central idea. These AI elements will not be discussed in this chapter, but only used for input to the second round questionnaire.

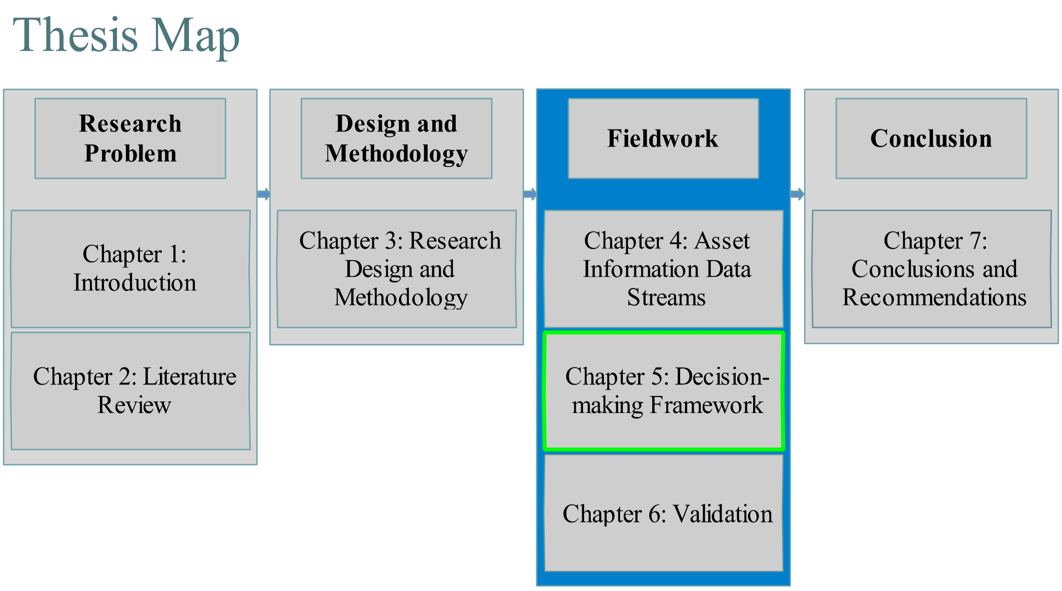
4.4 Chapter conclusion

This chapter started with a description of the first round data collection process. The results of the questionnaires were given and a section was dedicated to discussions and findings of the first round data collection.

In this chapter the first and second secondary research questions are answered and the third and fourth sub-objectives addressed. The significant decisions that are based on AI and influence operational availability in the SAN are identified. Correspondingly, the data streams of AI elements required to make such decisions were identified in the survey-based questionnaire. In the next chapter a preliminary framework is developed. This preliminary framework is used in the second phase data collection to determine the influence of each AI element identified in the first phase on operational availability of the SAN's systems. The results of the second phase data collection are consolidated into the SANAIDMF.

Chapter 5

Decision-making framework



In this chapter the second phase of data collection and construction of the SANAIDMF, which answers the third secondary research question, are reported. The chapter begins with the construction of the preliminary decision-making framework, which addresses the fifth research sub-objective. The preliminary decision-making is required for the second round of data collection during which the sixth research sub-objective is dealt with. After the second round data collection and analysis the SANAIDMF is presented. This satisfies the seventh research sub-objective. The research results are deliberated before the chapter conclusion.

5.1 Preliminary decision making-framework

The preliminary decision-making framework focuses on the information required to support decision-making towards achieving the required operational availability of systems in the SAN. Decision support is achieved by providing the decision-maker with an understanding of the AI elements in context. This includes which input data is required (based on the decisions to be made as identified by the decision-makers) and the impact of each AI element, positive as well as negative.

The input data for the framework, especially with respect to the effect of AI on operational availability, does not exist and must be elicited from user experts. It is thus subjective and could very possibly be inaccurate in some areas. The value of AI in SA Navy is uncharted territory, but as more emphasis is placed on this type of thinking, input data is likely to become more accurate and readily available. For this study the sources of data are limited to a few selected individuals. Greater numbers of participants would result in more precise and reliable input data to the framework. However, for this research, consideration should be given to the limitations imposed by the relative simplicity of the data available. The complexity of the framework should match the input data; as more accurate data becomes available the complexity of the framework can be increased.

On account of the fluidity of decisions and expected change of input data with respect to data requirements and accuracy over time, the framework is constructed in such a way to allow it to be tailored with ease.

5.1.1 Framework criteria

This framework has two major components: the decision-maker's input that is obtained by primary data collection methods, and the algorithm used. The algorithm includes MCDM principles as there are multiple criteria to consider. The criteria chosen are based on ISO 55000 (2014) which describes informed asset decisions and the realisation of value being based on the balance of cost, risk and benefit or performance. The criteria in this instance are thus Cost of Information, Value to Operational Availability (denoted in the framework as A_O) and Risk.

Risk is formally defined by ISO 31000 (2009) as: "the effect of uncertainty of objectives" with additional notes that this is related to a deficiency of information in understanding or knowledge of an event, change of circumstances, likelihood and consequences. In this definition risks are linked to objectives. For the purposes of this study the objective is to maximise operational availability by taking informed decisions. The risk component of AI elements is a broad term that questions the validity of an AI element's data content based on usefulness for decision-making or its consequential effect.

The IAM (2015) lists the requirements for good quality data as accuracy, completeness, consistency, validity, timeliness and uniqueness. Anything less negatively influences the ability of the decision-maker to use the AI for decision-making. Typical questions to ask when assessing risk in this case are: Is the data time-sensitive and likely to expire before needed for decision-making? What is the probability of not having data available or the wrong data entered? How accurate and reliable is the data? Is this information part of statutory requirements? Answers to these questions culminate in assigning a level of risk associated with a particular AI element in the context of decision-making.

Value is a peculiar concept. It is defined by the Oxford dictionary as: "The regard that something is held to deserve; the importance, worth, or usefulness of something" (Definition of value in English, 2019). ISO 55000 (2014) and IAM (2015) do not define value as a term, but provide an explanation of the concept. According to these two publications each organisation should determine for themselves what constitutes value. This is based on organisational objectives, the nature and purpose of the organisation and the needs of stakeholders. "Value can be tangible or intangible, financial or non-financial" (ISO 55000, 2014).

According to IAM (2015) an organisation's AI strategy should include the approach to defining AI requirements considering the costs of providing AI and the value of AI. Value is thus a highly subjective concept, which should, however, be defined in detail for each organisation or application. In this study the Value to Operational Availability criterion is the importance of each AI element towards achieving the required operational availability, as perceived by experts.

IAM (2015) stresses that although assets can contribute value individually, any real value contributions are typically only generated when these assets are connected together in a larger entity. This also holds true for information assets. Therefore, individual AI elements need to be evaluated by experts for their part in the whole, not as stand-alone assets. All the AI elements listed in the first round data collection are important for operational availability related decision-making. However, a differentiation must be made for the event that decisions must be made as to which AI elements to acquire and maintain.

This particular criterion is at the crux of this research, but cannot be studied independently as the other two criteria also have a profound effect, which influences AI-related decision-making.

Cost of Information is the monetary value of obtaining or maintaining the particular AI element. This could be difficult to isolate. For example, when it comes to software packages, AI is often managed by a central AI system with a fixed basic cost. Therefore, although in theory the Cost of Information criteria should be an objective allocation according to the real costs involved, the score assigned to this criteria is also expected to be subjective.

The MCDM method must thus take into account for assessment each AI element and its attributes in respect of each of the three criteria, Value to Operational Availability, Cost of Information and Risk.

5.1.2 Comparison of MCDM methods

In order to construct the decision-making framework, a MCDM method, upon which the algorithm of the framework will be based, must be decided on. MCDM problems can be used to solve sorting, choice or ranking problems (Ishizaka and Nemery, 2013). In this study a ranking problem must be solved as the decision-maker expects prioritisation of AI elements. Typical MCDM problems do not yield one perfect solution, but rather an optimised compromise (Ishizaka and Nemery, 2013; Hendriks *et al.*, 1992). This optimised compromise is a direct result of subjective stimulus provided by the decision-maker, where the decision-maker is central to the decision and the automation of decisions is not possible (Ishizaka and Nemery, 2013).

This decision-making framework is intended for strategic and tactical decisions, which typically have a medium- to long-term time perspective and thus an inherent low degree of structure and high degree of uncertainty. To mitigate uncertainty, constant stimulus adjustments by decision-makers are required as soon as new information becomes available, which will be made easier if some parts of the process are automated. This reinforces the argument of Hendriks *et al.* (1992) that although full automation is not possible, when deciding on an MCDM method a certain level of automation should be aspired to.

The ideal MCDM method for this problem must thus be simple enough for users to perform multiple stimulus update iterations as and when required. User interaction must be limited to the stimulus information as far as possible, and not require users to perform calculations. After grouping the alternatives on completion of the first round of research, the count is at 66 AI elements, with three attributes scores each, that must be considered as per the three criteria. That figure could change if the framework is tailored to other specific needs in future iterations, but it points to the fact that the MCDM method must be able to handle a large number of alternatives with ease.

Ishizaka and Nemery (2013) state that deciding with certainty which method makes more sense for a specific problem is almost impossible. A proposed method is examining the input information, data and modelling effort, together with the parameters of the method and the expected outcome (Ishizaka and Nemery, 2013). This basic method is used to decide on the MCDA tool to be used, starting by eliminating methods which are not ideal and then deciding between those which are feasible. The MCDM methods listed in Section 2.4 are used as reference for the methods to be considered.

AHP, PROMETHEE and ELECTRE all make use of pairwise comparisons in their steps towards providing a solution (Ishizaka and Nemery, 2013; Hendriks *et al.*, 1992; Marttunen *et al.*, 2017). The sheer number of alternatives in this decision-making framework makes the number of comparisons required too many. Using an example of AHP: with the 66 AI elements initially identified and making use of formula 2.4.1 it equates to 2145 comparisons that are required for each of the three criteria. The large number of alternatives that must be compared thus eliminates AHP, PROMETHEE and ELECTRE.

The ANP MCDM method poses the same challenges. In addition, ANP assumes dependencies between some criteria and structures the problem as a network (Marttunen *et al.*, 2017). There are no dependencies between criteria in this framework, although if structured with different criteria ANP could possibly be used to investigate emergent properties of AI elements. That is, however, outside of the scope of this study. ANP is therefore also not a viable method for use in this decision-making framework.

DEA is mainly used for performance measurement, not relying on subjective inputs but rather on linear optimisation to show each alternative in the best light (Ishizaka and Nemery, 2013; Velasquez and Hester, 2013). The MCDM method used in this framework should be able to use imprecise subjective input. DEA is thus also not the ideal candidate.

Fuzzy set theory has been used in ranking problems, but it is commonly used in combination with other MCDM methods (Bojadziev and Bojadziev, 2007). Fuzzy theory is therefore not completely eliminated, but kept in reserve only to be used should another MCDM method not be found and a hybrid MCDM mix prove to be required.

TOPSIS and MAUT are both feasible options. TOPSIS was developed by Hwang and Yoon as a technique to assess the performance of alternatives by comparing it to the ideal solution, as well as the anti-ideal solution (Krohling and Pacheco, 2015). The ideal solution is one that maximises the beneficial criteria and minimises the negative criteria, with the anti-ideal solution being the opposite. Traditional TOPSIS attempts to rank alternatives according to those which simultaneously have the shortest distance from the ideal solution as well as the farthest from the anti-ideal solution (Behzadian *et al.*, 2012).

Due to the its simplicity, TOPSIS, or hybrid-TOPSIS, has seen applications across a range of fields, including logistics, design engineering, manufacturing, business and supply chain (Behzadian *et al.*, 2012; Velasquez and Hester, 2013). To apply TOPSIS, the attributes of the alternatives must be numeric, monotonically increasing or decreasing and have comparable units (Behzadian *et al.*, 2012). The preferences need not be independent, which could lead to illogical results (Ishizaka and Nemery, 2013; Behzadian *et al.*, 2012).

To carry out TOPSIS methodology the following procedure must be followed according to Ishizaka and Nemery (2013) and Behzadian *et al.* (2012):

Step 1 Construction of a normalised decision matrix that contains the criteria and associated parameters of the alternative.

Step 2 Construction a weighted normalised decision matrix where the weights of each criterion are factored in.

Step 3 Determination of the ideal and anti-ideal solutions, as per the normalised decision matrix.

Step 4 Calculation of the distances from the ideal and anti-ideal solutions for each alternative.

Step 5 Calculation of the relative closeness for each alternative using both distances from ideal and anti-ideal solutions.

Ishizaka and Nemery (2013) are, however, of the opinion that should it be possible to construct a utility function, MAUT should be used for MCDM problems. MAUT is based on the idea that every decision-maker is attempting to optimise a function which combines their viewpoints, albeit subconsciously. This implies that the decision-maker's preferences can be depicted in a utility function, which is not always initially known but must be constructed during the decision-making process.

Three common types of decision-making problems relating to the decision-maker's knowledge about the plausibility of events occurring are: decisions under certainty, decisions under risk and decisions under uncertainty (Abdellaoui and Gonzales, 2013). The nature of decision-making under certainty is such that the utility function is unchanged as there is no change in outcome. When making decisions under risk and uncertainty the utility function could change, depending on the outcome of events. Thus, probabilities are assigned and incorporated into a stepwise utility function by means of probability and consequence sets, which are called lotteries (Abdellaoui and Gonzales, 2013).

However, in the case of this research so little information exists that probabilities cannot be assigned to alternatives and possible outcomes. It must thus rely on creativity by the group of participants selected to succeed. This is especially true for the Value to Operational Availability and Risk attributes of the alternatives. The MAUT weighted sum method allows participants to discount the complexities brought about by uncertainty by the assumption of linearity in preferences. For practicality, uncertainty is thus suppressed, providing an expert opinion without a probability. Making use of a probability is more accurate when attempting to model actual conditions. But when there is so much uncertainty involved, the probability assigned by participants is just as likely to be inaccurate as the value itself. As uncertainty decreases, complexity in attempting to model reality can be added and a process model developed. However, as explained in Section 1.5 a model falls outside this scope of this study. The intention is to create a framework for understanding the interactions of AI elements amidst formidable uncertainty.

The MAUT weighted sum approach is very similar to TOPSIS. Ishizaka and Nemery (2013) however describe the weighted sum method as unrefined. This is due to the assumption of linearity in the preferences, where non-linear utility preferences are sometimes a more accurate reflection of reality. Ishizaka and Nemery (2013) continue by describing the MAUT weighted sum method as a naive approach, but also state that it is a: "special case of a more complex method" and, with the correct precautions yields sensible outputs. Chief amongst the precausations listed is independent criteria, also called 'preferential independence', which TOPSIS does not require. Besides preferential independence, the reasoning and procedure for a MAUT weighted method and traditional TOPSIS are very alike. The weighted sum MAUT procedure is as follows (Ishizaka and Nemery, 2013; Abdellaoui and Gonzales, 2013):

Step 1 Denote by F the set of q criteria f_j $(j = 1,....,q)$

Step 2 Evaluation of alternatives $f_j(\mathrm{a_i})$, inversing the criteria that must be minimised

Step 3 Develop the utility function from user preferences. In the additive method the general utility function is as follows:

$$U(a_\mathrm{i}) = U(f_1(a_\mathrm{i}), \ldots, f_\mathrm{q}(a_\mathrm{i})) = \sum_{j=1}^{q} U_\mathrm{j}(f_\mathrm{j}(a_\mathrm{i})) \times w_\mathrm{j} \qquad (5.1.1)$$

However, in the weighted sum method linearity of the utility functions are assumed and the utility function is as follows:

$$U(a_{\mathrm{i}}) = \sum_{j=1}^{q} f_{\mathrm{j}}(a_{\mathrm{i}}) \times w_{\mathrm{j}} \tag{5.1.2}$$

where the weights represent the preference of the decision-maker towards certain criteria. One criterion's gain is another's loss and weighting indicates how many units of one criterion the decision-maker is prepared to lose to gain units on the preferred criterion. Weights are normalised

Step4 The weights attached to the criteria and the utility contributions are inserted into the utility function for each alternative. As per equation 5.1.2 a summation yields the final utility score of each alternative.

Step 5 The scores of the alternatives are ranked from high to low

Preferential independence and the benefits associated with it are thus the major distinguishing factor between using TOPSIS and MAUT in this instance. Preferential independence for this framework is ensured through the assumption of linearity of the preference criteria and real number inputs from experts.

Therefore, considering the above, the MAUT weighted sum method is chosen as the algorithm to be used in the decision-making framework.

5.1.3 Framework development

As explained above, there are two components to the framework: data collected and an algorithm to process it with. The data collected in the first round forms the basis of the framework. The algorithm, in conjunction with further data input, provides the final decision-making framework: the SANAIDMF. The SANAIDMF is meant to be a dynamic framework which, by means of changes in input information, helps the decision-maker understand phenomena regarding AI in the SAN.

The development of the framework must consider user friendliness by allowing decision-makers to change input data, whilst remaining isolated as far as possible from performing lengthy calculations when changing inputs. To meet this requirement, Microsoft Excel is chosen as the software tool. It is widely used and understood software and it allows for the automation of calculations. The results from the first round data collection are inserted into Excel and transposed, to make the AI elements listed the main subject and the decisions linked to them the hangers-on. In contrast to the first questionnaire the decisions taken are not the main focus of the framework, but are used to provide context pertaining to the demand and criticality of the particular

AI element. The next step requires an algorithm to be added.

Using Excel, a preliminary framework is constructed. As discussed, the MAUT weighted sum method is chosen as the primary MCDM method. The preliminary framework, complete with the MCDM method built in, is used to gather the second round data, the only difference between the preliminary framework and the SANAIDMF being that the data input from subject matter experts is included in the SANAIDMF. To gather the data required for the SANAIDMF, user experts are firstly asked to provide their criteria preferences for the construction of the utility function. Mikoni (2012) suggests using a scale for value-based estimation by experts instead of the typical von Neumann and Morgenstern 'lottery' approach to determine the utility function for linear additive models. This process is the same as that of AHP where pairwise comparisons are used to determine the criteria weights.

AHP was developed by Saaty as a theory of measurement that relies on the judgements of experts to elicit priority scales through pairwise comparisons (Saaty, 2008*b*). Velasquez and Hester (2013) describe AHP as one of the most popular MCDM methods, based on both mathematics and psychology it allows decision-makers to weight criteria with relative ease. It provides a means to break down a problem into a hierarchy of sub-problems, which are easier to evaluate (Hossain *et al.*, 2014). Hossain *et al.* (2014) continues by stating that by using pairwise comparisons for the assessment of criteria, a linear additive model is developed. Typically, a decision-maker is asked to compare two criteria and using a 1 to 9 scale indicate the degree of importance of one criteria in relation to the other being evaluated (Ishizaka and Nemery, 2013; Saaty, 2008*a*). However, research by Hossain *et al.* (2014) shows that using a 1 to 5 scale is as effective as using a 1 to 9 scale, with the 1 to 5 scale being more user-friendly.

The AHP paired comparison matrix with a 1 to 5 scale is thus used in the second round questionnaire to weight criteria for the construction of the MAUT utility function. This algorithm will be referred to from here on in this thesis as an AHP-MAUT hybrid.

In the absence of accurate data for each alternative with reference to the criteria, experts are asked to allocate alternative attribute scores. This is done on a crisp rating scale from one to ten. It is expected that due to the familiarity and simplicity of the well-known one to ten rating scale experts are able to assign scores quicker and more accurately, bearing in mind the large number of alternatives presented to them.

The AHP-MAUT approach for the preliminary framework involves the following steps:

Step 1 - Denoting criteria Let f_1 = Value to A_O, f_2 = Cost of Information and f_3 = Risk

Step 2 - Evaluation of alternatives Evaluation of alternatives with reference to the criteria are dependent on input from subject matter experts. This input is obtained from the second round data collection's questionnaire, where each alternative's attributes are scored on a rating scale by the subject matter expert.

Using a 1 to 10 rating scale for all three criteria provides for comparable attributes.

Step 3 - Developing the utility function This also requires user input which is obtained in the second round data collection. AHP methods, as discussed above, are used in a paired comparison matrix to obtain a weighted score for each criteria. The number of comparisons are governed by equation 2.4.1. With three criteria there are three pairwise comparisons required.

Step 4 - Utility score of each alternative The utility score of each alternative is calculated using formula 5.1.2.

Step 5 - Ranking of scores The scores are ranked according to the utility scores obtained.

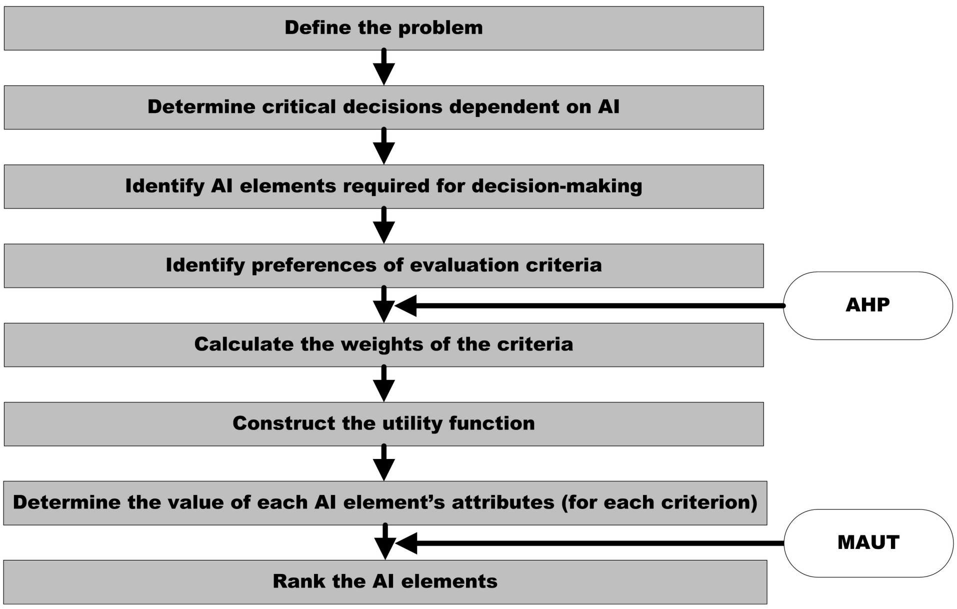


Figure 5.1: Schematic diagram of the proposed framework

The diagrammatic representation of the proposed framework is shown in Figure 5.1.

5.2 Second round data collection

In the first round of data collection a value chain was established from AI elements via decisions made to achieving the required operational availability of SA Navy assets. The second round of data collection used the data collected in the first round and focused on quantifying the contribution of elements in this value chain, together with their weaknesses. The utility function is also constructed from data collected in the second questionnaire. The aim of this round of data collection is to uncover the significance of AI elements to better the decision-maker's understanding and ultimately aid decision-making when used in the SANAIDMF.

As discussed above, MCDM methods are used to carry out the research with the ultimate objective of developing an AI decision-making framework for the SAN. The two steps in the second round data collection are envisaged to be repeated by decision-makers as updates to input information are made.

5.2.1 Data collection process

A survey-based questionnaire is the method chosen for the second round data collection. In the questionnaire closed-ended questions, based on the outcome of the first round of data collection and a hybrid AHP-MAUT algorithm, are used (see Appendix D). Prospective participants are selected as explained in Section 3.3.1. Similar to the first round, appointments are made with prospective participants where the questionnaire is explained. If the participant agrees to partake in the study a period of two weeks is given after which another appointment is scheduled to collect the questionnaire.

5.2.2 Questionnaire outcome

Four prospective participants were identified, three of whom agreed to partake in the study and completed the questionnaire. The fourth participant cited a lack of free time due to extraordinary work commitments as the reason for not completing the questionnaire.

Details of the participants, relevant to the validity of the answers, are displayed in Table 5.1.

Table 5.1: Encoded participant information for the second round data collection

Participant code	Current post title and responsibilities	Experience in this field
Participant A	**Director Naval Engineering (2009 – 2018)** Retired	38 years
Participant B	**Manager ILS** Configuration Control and Logistic Element Support	40 years
Participant C	**Acting Head of Logistic Engineering** Providing the following services: Logistic Support Analysis, Integrated Logistic Plans Development, Support System Design, Specification and Verification and specialist services in the development of logistic support baselines	11 years

5.2.3 Second round data analysis

The number of participants is too small for advanced inferential analysis. Instead, basic descriptive statistics that provide means and standard deviations are shown in Appendix E. This is done for the preference scores and each of the sixty six element's three attribute scores.

To construct the utility function a pairwise comparison matrix is used. Participants choose their preference and also provide a trade-off ratio score. From this a relative weight expressed as a percentage for each of the three criteria is calculated. The criteria weights of each survey are used to determine the global criteria weights by calculating the mean values. The standard deviation is also calculated as an indicator from which accuracy can be gauged.

The analysis shows that the Value to Operational Availability criterion is preferred more than the other criteria, with a mean value of 40% and standard deviation of 9%. This is followed by Risk, with a mean value of 33% and no standard deviation. Cost of Information is the least preferred with 27% and a standard deviation of 9%. The relatively small standard deviation indicates that there is consistency in the preference of criteria amongst the participants. This provides confidence in the preference values obtained.

Similar to the preference weighting, the values provided for each AI element's attributes in the surveys are used to calculate a mean value and a standard deviation. This is shown in Appendix E. The range of possible values that the participants could provide is between 1 and 10. The analysis shows that 43 of the Value to A_O scores, 45 of the Cost of Information scores and 40 of the Risk scores have a standard deviation greater than 2. That works out to 65% of the scores allocated by user experts with a standard deviation greater than 2, with 22% having a standard deviation between 1 and 2 and 14% of the scores with less than 1. This does not provide as much confidence in the mean values as with the preference values and is discussed in detail in Section 5.4.

5.3 South African Navy asset information decision making framework

The mean values of the data collected in the second round data collection are inserted into the preliminary framework. It is processed as per the algorithm discussed in Section 5.1.3 and the first iteration of the SANAIDMF as displayed in Appendix F is the result.

Due to the organisational focus, requirements and the decisions that realise value not being static, the framework is also not intended to be static. The initial round of data collected took a survey across various asset classes in the SA Navy. When taking a survey, not SA Navy-wide, but into a specific asset class, tailored results with possibly a new mix of AI elements are anticipated. Therefore, more iterations with different input data are expected.

Although the process can be replicated from its origins (as per the first round data collection) it is envisaged that the first step, ascertaining which decisions must be taken and what the AI requirements are for these decisions, will be carried out by the decision-maker without formalising it in the SANAIDMF. Changes to the input information of the SANAIDMF will then occur when the preferences of decision-makers change, or when addition or subtraction of AI elements according to AI requirements takes place. The attributes of various AI elements can also change if more accurate data becomes available. That being said, the first iteration of the SANAIDMF is constructed using data gathered from the current experts available in the SA Navy and also thoroughly validated. It is thus a suitable baseline from which to benchmark and form an understanding of how AI elements interact in the SA Navy context, despite all the changes envisaged.

There are thus two facets of the SANAIDMF. The first is the research output in Appendix F. The second facet is the changing nature of the framework: the top-down method of enquiry coupled with the MCDM-based algorithm in a user-friendly Excel format. The second facet can be used to produce more outputs such as the first iteration, only with greater input information accuracy or tailored to specific requirements. As each iteration's results will be different, it is difficult to predict which data analysis methods and statistical tests could be carried out on the results of future iterations to provide more insight and meaning to decision-makers. However, in Section 5.3.1 the results of statistical tests performed on the research data set of the first iteration of the SANAIDMF is discussed. Additional insights and recommendations for the use of the SANAIDMF will be provided. All of this might then prove useful for future iterations.

5.3.1 Using the decision making framework

There are 66 ranked AI elements in the first iteration of the SANAIDMF. The rank of the AI elements are determined by the utility score, where the utility score is defined by Ishizaka and Nemery (2013) as: "the degree of well-being those alternatives provide to the decision-maker". Thus, besides providing the values used to rank the AI elements with, the utility scores provides an indication of usefulness to decision-makers. This decision-making process revolves around obtaining and maintaining AI, with the SANAIDMF providing input as to the importance, or usefulness, of AI elements in ultimately reaching the organisational objectives of the SAN, represented by A_O in this thesis. The higher the utility score, the more resources should be afforded to an AI element. On the other hand, should less resources be available, not obtaining and maintaining AI elements with lower scores will have the least impact on A_O.

The utility scores, and the differences between them, can be critically examined to provide insights into the results of the SANAIDMF. Firstly, differences between utility scores provide insight with regard to the relative value of each AI element. Significantly higher scores indicate that certain AI elements, or perhaps clusters of AI elements are significantly more important than those ranked directly lower. Secondly, although all AI elements listed are of some importance in achieving organisational objectives, there should be a logical divide to indicate which AI elements must have priority. There will be diminishing returns lower down on the ranked list.

There were three respondents to the second round data collection who each provided a data set. In each data set a utility score for each of the 66 elements is calculated. The three individual scores are used to calculate a mean utility score value for each AI element (see Figure 5.2). The mean values of the AI elements are then used to rank the AI elements (see Figure 5.3.)

To investigate the significance, if any, of the interval between the mean utility scores of AI elements a mixed method analysis of variance is performed

		Utility Mean	Utility Std. Dev.	UT(1)	UT(2)	UT(3)
Accurate costing of spares and materials	Item 1	5,723	0,526	5,680	5,220	6,270
Accurate job-card feedback	Item 2	5,837	1,017	7,010	5,220	5,280
Allowances of original design parameters such as weight increase, load increase, usage increase as well as structural strength and integrity.	Item 3	6,693	2,891	3,850	9,630	6,600
Budget information	Item 4	8,183	1,916	6,010	9,630	8,910
Capacity of repair sections to conduct outstanding maintenance	Item 5	7,087	2,212	6,020	9,630	5,610
Consumable products allowance lists	Item 6	7,140	2,175	6,180	9,630	5,610
Accurate costing of services required	Item 7	5,557	0,618	5,180	5,220	6,270
Data showing the difference between predicted hours and material vs actual hours and	Item 8	5,280	0,961	4,350	5,220	6,270
Design change impact studies	Item 9	5,530	0,070	5,500	5,480	5,610
Divisions between mission critical spares and all planned spares	Item 10	4,903	2,370	6,840	2,260	5,610
Equipment required	Item 11	6,740	1,491	6,680	8,260	5,280
Equipment sensitivity towards number of uninstall and install procedures	Item 12	6,767	1,693	4,820	7,890	7,590
Expiration dates of stock in depot	Item 13	5,413	2,453	6,350	2,630	7,260
Failure rate data	Item 14	5,440	0,434	5,160	5,220	5,940
Handover procedures (record keeping)	Item 15	6,230	2,029	4,850	8,560	5,280
Historical cost data	Item 16	6,753	1,215	6,170	8,150	5,940
Human resource personnel shortage prevention measure strategies	Item 17	7,170	1,437	5,690	8,560	7,260
Human resource strategies and plans to replace maintenance personnel with suitably qualified stand in personnel	Item 18	7,230	1,189	6,860	8,560	6,270

Figure 5.2: Screenshot of the individual utility scores used to calculate the mean utility scores

using the three individual utility scores as input. The purpose of the test is to determine if there are statistically significant differences between any of the elements, or possibly clusters of elements. For the purposes of this test the hypothesis is that the mean values of AI elements compared are equal. The p-value calculated represents the probability that the mean value could be the same for the AI elements being compared, given the $n = 3$ sample size. Statistically significant differences between AI elements only exist when the $p \leq 0.05$. This statistical analysis is performed in Statistica and the results are shown in Figure 5.4 and Appedix G[1].

The results show that the intervals between the adjacent ranked AI elements, or any local AI element clusters, are not statistically significant. This implies that no distinction can be made between any two AI elements, or local clusters, based on the difference between their utility scores. The lack of statistical significance is attributed mostly to the small number of participants $n = 3$ coupled with a high standard deviation. Even though there is no statistical significant indication, what is clear from observation is that interval between the first and second ranked AI elements is larger than the interval between any other two AI elements (see Figures 5.3, 5.4 and 5.5). Although already highest ranked, 'Budget Information' is notably of more important in

[1]In the results reference is made to 'Items' instead of the normal convention of AI elements used in this thesis. 'Item' was used in Statistica for brevity as the description of some AI elements are very long and will clutter the output graphs and tables. Before sorting the AI elements according to rank they were sorted in alphabetical order and labelled item 1 to item 66. When ranking the elements the item numbers move with their AI elements. To find the AI element corresponding to a particular item in Figure 5.4 and Appedix G reference can be made to Figure 5.4 or Appendix F

	Asset Information element	Utility Score	Rank - descending order of preference
Item 4	Budget information	8,183	1
Item 18	Human resource strategies and plans to replace maintenance personnel with suitably qualified stand in personnel	7,230	2
Item 17	Human resource personnel shortage prevention measure strategies	7,170	3
Item 6	Consumable products allowance lists	7,140	4
Item 5	Capacity of repair sections to conduct outstanding maintenance	7,087	5
Item 66	Work to be performed during maintenance or alterations to equipment	7,030	6
Item 46	Projected missions	6,970	7
Item 59	Supply lead times	6,927	8
Item 61	Turnover amount of stock	6,910	9
Item 49	Required delivery schedule	6,793	10
Item 12	Equipment sensitivity towards number of uninstall and install procedures	6,767	11
Item 63	Upcoming maintenance requirements	6,753	12
Item 16	Historical cost data	6,753	13
Item 45	Projected equipment priorities	6,750	14
Item 11	Equipment required to perform maintenance and alteration work on equipment	6,740	15
Item 52	Status of training material and training aids	6,730	16
Item 3	Allowances of original design parameters such as weight increase, load increase, usage increase as well as structural strength and integrity.	6,693	17
Item 32	Number of candidates for refurbishment	6,687	18
Item 19	Industry support contract information	6,650	19
Item 48	Readiness level required	6,573	20
Item 41	Period by which the maintenance downtime will be extended to catch up on maintenance once the product system is no longer operationally required	6,460	21
Item 54	Stock usage history	6,447	22
Item 62	Unplanned breakdown information	6,417	23
Item 51	Status of training facilities	6,400	24
Item 35	Number of mission related products to be procured	6,390	25
Item 58	Supplier production planning	6,380	26
Item 44	Product lead time	6,360	27
Item 15	Handover procedures (record keeping)	6,230	28
Item 27	Maintenance history	6,180	29
Item 31	Modification instructions	6,147	30
Item 43	Previous refurbishment details	6,027	31
Item 20	Information on alternatives available in the market	5,963	32
Item 57	Supplier data	5,957	33
Item 36	Number of products likely to require modifications	5,917	34
Item 40	Original product system acquisition plan	5,870	35

Figure 5.3: Screenshot of the top section of the SANAIDMF

achieving operational outcomes than any other AI element and should thus be managed as such.

Using the least significant difference post hoc table in Appendix G three different priority groups of AI elements are identified by their $p-values$. Each AI element's $p-value$ in comparison to the highest ranked AI element, Item 4, is noted. The distinction between groups is made when that AI element falls outside of the 95% confidence interval thus $p \leq 0.05$ and again when $p = 0$. The highest priority items to concentrate resources on are indicated under the blue horizontal bar in Figure 5.4. There are 31 items under the first bar, from Item 4 to Item 43 on the horizontal axis. The second (red) bar indicates the AI elements that are medium priority. There are 32 AI elements under this

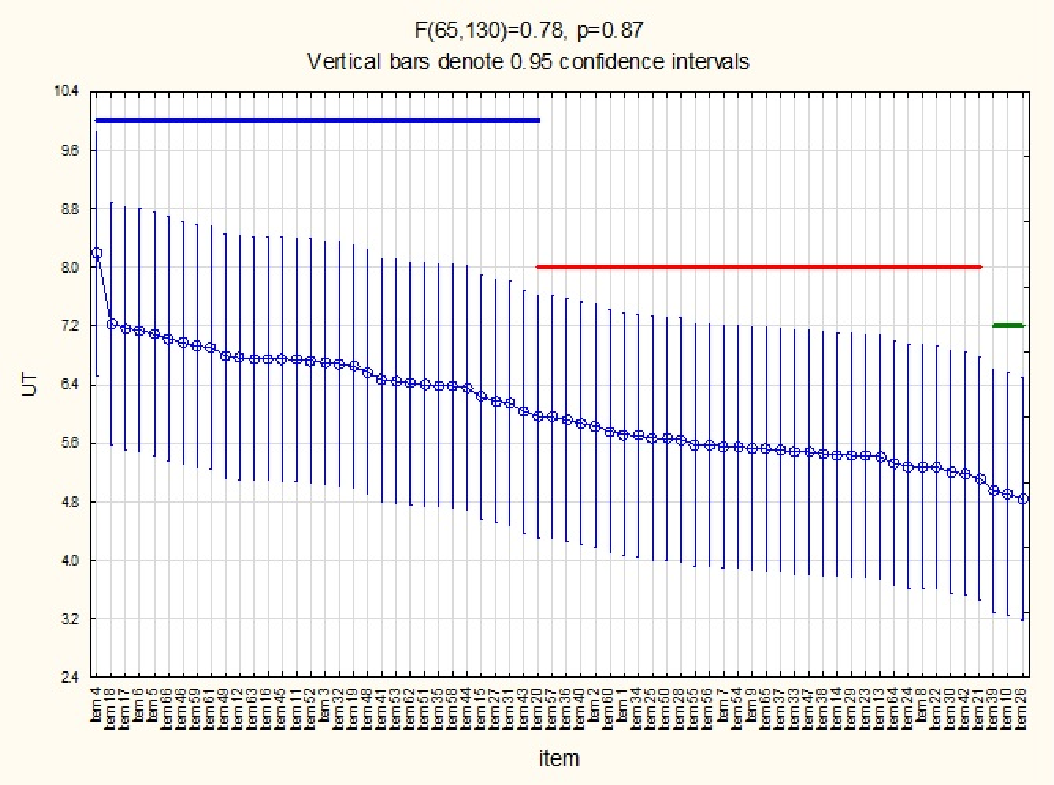


Figure 5.4: Element least significance means graph

bar, from Item 20 to Item 21. The group that is the lowest priority is indicated with the green bar. There are three items in this group, from Item 39 to Item 26.

The SANAIDMF is created in Excel to be user friendly and allow for numerous iterations. However, the statistical analysis performed for this thesis cannot be automated in Excel and will require advanced analytical software to perform, which might not be available to all envisaged users. The analysis must thus be catered for in future iterations of the SANAIDMF.

In addition to obtaining and maintaining AI elements according to the priority recommendations, action can be taken to increase the utility score of selected lower ranked AI elements. This also does not require advanced analysis to determine the candidate AI elements. By increasing the utility score of an AI element its usefulness in achieving organisational objectives is increased.

The three attributes contributing to the utility score are *Value to* A_O, *Cost of Information* and *Risk*. The *Value to* A_O is unlikely to change, but the action can be taken to reduce the *Cost of Information* and *Risk*. These actions intended to mitigate the negative effects on an AI element must only be taken

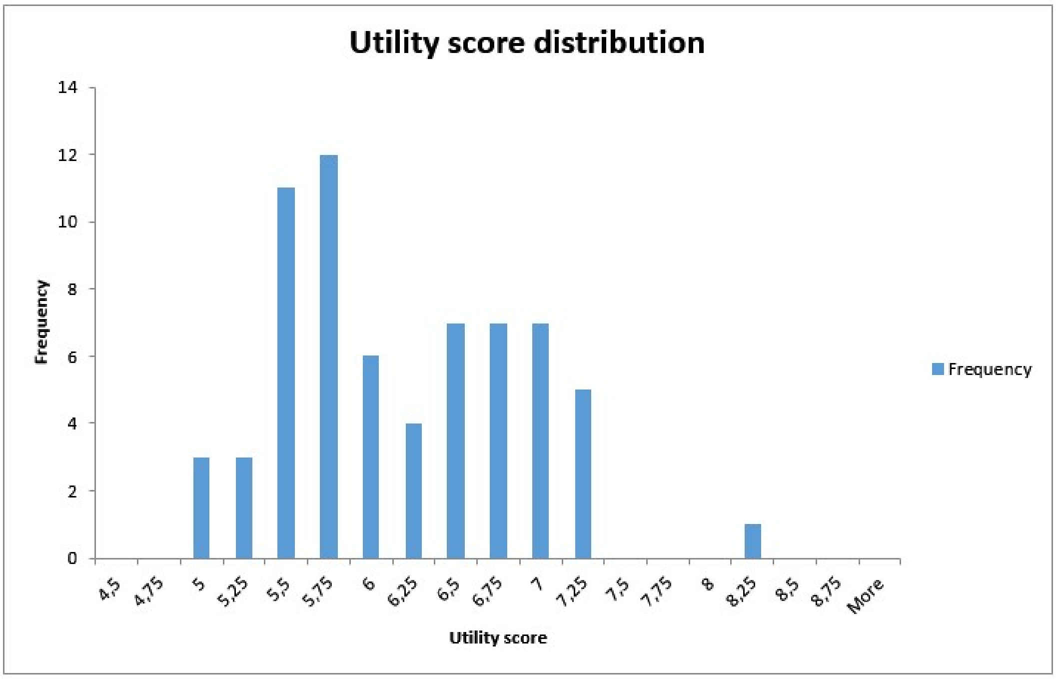


Figure 5.5: Utility score distribution

in the case where the AI element has a high *Value to* A_O score, 8 or more is recommended. Coupled to that, the AI element should also have an high (negative) *Cost of Information* and *Risk* score; recommended that an mean score of 7 or above be considered. Candidates with these values are indicated in Figure 5.6.

These recommended scores can be adapted as the decision-maker sees fit, whilst applying the philosophy of increasing the utility score of an AI element with potential by reducing that which negatively affects the utility score. Root causes that affect the *Risk* associated with AI elements, especially those that affect more than one AI element, should be identified and mitigated. Similarly, process improvement could decrease *Cost of Information* in the case of 'in service feedback data'. However, the specifics and range of actions that can be taken to reduce the cost and risk of AI elements fall outside the scope of this thesis and will not be discussed further.

In using the output of the SANAIDMF decision-makers can thus prioritise AI elements according to the outcome of statistical analysis of the utility scores. Measures can also be put in place to mitigate factors negatively affecting the utility scores of AI elements, based on the attributes scores contributing to the utility score, thereby making AI more useful to the organisation. As a combination of these recommendations, it is further recommended that business rules and strategies be adapted accordingly in order to optimize the cost

	Asset Information element	Attributes (Scale 1 to 10)			Utility Score	Rank - descending order of preference
		Value to Ao	Cost of Information	Risk		
Item 50	Spares required for preventive and corrective maintenance as well as alterations on equipment	9,333	6,333	8,333	5,663	41
Item 28	Maintenance task information	7,667	7,333	5,667	5,653	42
Item 55	Studies detailing the overall effect on operational availability if some sub systems are being used more than originally planned	6,000	7,000	4,000	5,577	43
Item 56	Studies on the long term effect of delaying maintenance on the product system	5,667	7,333	3,333	5,573	44
Item 7	Accurate costing of services required	7,333	6,333	5,333	5,557	45
Item 53	Strategies to reduce readiness and usage levels to ease the utilization of equipment	5,667	4,667	3,000	5,550	46
Item 9	Design change impact studies	4,667	5,667	3,000	5,530	47
Item 65	What if scenario's and strategies related to reducing the number of available systems, maintenance of sub-systems, changing maintenance philosophy and changing training policies	6,333	8,000	3,667	5,520	48
Item 37	Number of products requiring scheduled maintenance	8,667	6,000	8,000	5,510	49
Item 33	Number of each type of mission related products to be re-supplied	7,000	5,667	6,667	5,480	50
Item 47	Qualified OSBL	7,667	6,667	7,000	5,477	51
Item 38	Number of systems required to be online in a given period	7,333	7,333	5,333	5,453	52
Item 14	Failure rate data	7,333	7,667	5,333	5,440	53
Item 29	Materiel and usage accounting	6,333	6,333	5,000	5,433	54
Item 23	Information on what proportion of repairs are likely to take place at each level of maintenance	7,000	7,667	5,000	5,427	55
Item 13	Expiration dates of stock in depot	5,667	4,000	6,667	5,413	56
Item 64	Usage history	6,667	7,667	4,667	5,327	57
Item 24	Inventory levels	7,667	6,333	6,667	5,283	58
Item 8	Data showing the difference between predicted hours and material vs actual hours and material used per standard maintenance task	6,333	6,000	5,333	5,280	59
Item 22	Information on the availability of skills and special tools at the relevant maintenance level	7,000	6,000	6,333	5,270	60
Item 30	Minimum stock levels	6,667	7,000	5,667	5,210	61
Item 42	Predicted stock usage for planned activities	8,333	6,667	8,000	5,187	62
Item 21	Information on systems being operated in other military environments	3,333	6,000	3,333	5,120	63
Item 39	OEM Last time buy and technical support information	7,000	8,333	5,667	4,953	64
Item 10	Divisions between mission critical spares and all planned spares	5,000	6,000	5,333	4,903	65
Item 26	LSA data	7,000	8,667	6,000	4,843	66

Figure 5.6: Screenshot of the bottom section of the SANAIDMF

versus benefit ratio, enhance AM proficiency, sustain military capabilities and meet the organisational objectives of the SA Navy.

5.4 Results deliberation

The results emanate from user input and the data collection and processing methodology. Data is collected in two rounds, both using a survey-based questionnaire. It is then processed using a AHP-MAUT algorithm. In the author's opinion there are two contentious issues in the results: the AI elements listed and a high standard deviation associated with of some of the AI elements attribute scores.

The high values for the standard deviations can be contributed to a number of factors:

Firstly The second round participants had different interpretations of the elements and their attributes than the first round participants. The elements were identified by a different set of participants from those who assigned attribute scores, and without context each participant in the second round used his own interpretation of the element attributes to assign a score.

Secondly The abstract concept of assigning scores to the attributes of each element without a point of reference available made it difficult for the participants to ground their opinion. A reference could for example be in the form of an existing data-set. Each participant thus had a different point of reference from which the elements were scored.

Thirdly The pool of participants is very small. Unless there is consensus amongst the participants, the standard deviation will be high.

With such a small pool of possible participants high standard deviation values could be mitigated in future iterations of the SANAIDMF by carrying out a Delphi study, possibly also using the scores obtained during the second round data collection as reference. Amos and Pearse (2008) state that the Delphi technique generates data that would be impossible to obtain otherwise. The technique develops phenomena which are difficult to model where the available historical data is incomplete, provides little insight, is inaccurate or totally unavailable (Amos and Pearse, 2008; Linstone and Turoff, 2002). A benefit according to Okoli and Pawlowski (2004) is the ability to build an understanding of the relationships between elements by requesting the participant to justify their responses. This will provide the participants with the opportunity to benchmark and build their opinions based on the justifications from other participants, eventually leading to consensus and therefore confidence in the AI element's attribute scores.

The AI elements are elicited using a top-down method, where decision-makers were initially asked: '*In your opinion, which decisions are made that affect the availability of systems in the South African Navy (SAN)?*' The AI elements required for the decision-maker to make this decision are then subsequently listed, scored and ranked. However, the decisions listed might not be the correct ones. The author is of the opinion that how the question was asked in the questionnaire led to the decision makers listing questions that they struggle with at the present moment.

The decisions emanating from the first survey, as seen in Appendix C, tend to revolve around issues originating from a declining budget. Although these decisions and related AI element requirements have a representative spread amongst those found in literature (explained in detail in Section 4.3), there is much more focus on reactive type budget, maintenance, repair and obsolescence decisions. It was expected to see more proactive strategically orientated decisions and AI element requirements. However, at the time of answering the questionnaires that was the most important issue facing the decisionmakers in attempting to achieve operational availability. A few months after the participants completed the questionnaire the Chief of the SA Navy briefed the Parliamentary Joint Standing Committee on Defence that the SA Navy is in danger of losing the complete Frigate and Submarine capability due to declining budgets (Wingrin, 2019).

Although the budgetary issues coming to the fore bolster the intent and methodology of this thesis, limiting the focus at the origins of the inquiry narrows the scope of the results. A question guiding the decision-maker to focus on what should be decided on if all current constraints are removed might have yielded a wider range of AI elements. However, for the decision-maker to focus on a wider range of AI elements whilst the main constraint remains budget could also not be optimal. Two distinct scenarios should be incorporated, the present situation and a desired future state based on the strategic goals of the organisation. Making use of various iterations of the SANAIDMF, changing inputs and incorporating a Delphi method to benchmark responses, is thus highly recommended.

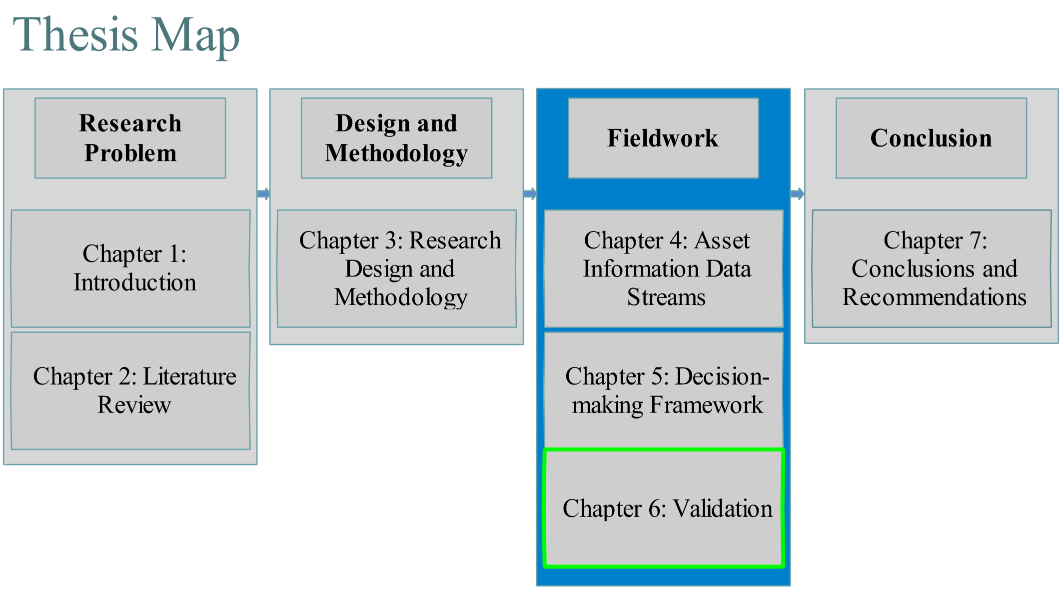
5.5 Chapter conclusion

This chapter started with the construction of the preliminary decision making framework where the criteria and MCDM algorithm were discussed. Following this the second round of data collection was addressed. The SANAIDMF was presented before the results of the research were deliberated.

In this chapter the fifth, sixth and seventh research sub-objectives were addressed. They are to construct a preliminary framework, determine the influence of AI elements on the SAN's operational availability and consolidate those into a decision-making framework. The third research question is: How can a framework be constructed to understand the impact of each of the AI elements on operation availability? This was answered by achieving the above sub-objectives. In the next chapter the focus is on the eighth research sub-objective - Validating the SANAIDMF.

Chapter 6

Validation of framework



The aim of this chapter is to validate the SANAIDMF and achieve the eighth sub-objective. Validating the results is a necessary step to gain confidence in the outcome of any research project. To gain this confidence the research design should be suited for the purpose of the research undertaken and be able to answer the research questions (Welman *et al.*, 2005) . Validity is thus crucial to the integrity of this thesis and its conclusions. In this chapter a short introductory discussion on validation leads to a discussion on the validation methodology used for the SANAIDMF. Success factors and the expert panel are discussed before the results of the validation process are provided. The chapter conclusion follows. With validation the sub-objectives contributing to the primary research question are achieved, meaning that the primary research question will be answered after successful validation.

6.1 Validation introduction

Creswell (2013) states that when making use of the exploratory sequential mixed research design, the researcher should check the validity of the qualitative research and quantitative research. The validity in qualitative research assesses the accuracy of the findings from the viewpoint of the readers or participants (Creswell, 2013). Welman *et al.* (2005) describes validity as the degree of accuracy to which the research results represent the actual situation, whereas the method of inquiry is valid if it measures what a researcher claims it does. Creswell (2013) adds that there are three traditional forms of validity: content validity, predicted validity and construct validity. In recent studies the focus has shifted to construct validity; ensuring that the measuring instrument measures what is intended and that the results serve a useful purpose in the context of the research (Creswell, 2013; Welman *et al.*, 2005). Construct validity will thus form part of the success factors and is discussed in Section 6.2.

In quantitative research, validity does not have the same connotations as it has in qualitative research; nor is there a complementary relationship with reliability (Creswell, 2013). According to Creswell (2013) quantitative validity is concerned with whether useful inferences can be drawn from scores. In this research there are, however, no inferences drawn from the scores, making reliability more significant. Reliability is concerned with the credibility of the findings and if they are repeatable when applied to new participants, settings or by a new researcher (Creswell, 2013; Welman *et al.*, 2005; Blaxter *et al.*, 2006). Reliability is partially checked with user validation (discussed in Section 6.2), and partially by the procedures used during the research as discussed below.

To ensure reliability in this thesis all completed surveys are scanned and electronically stored. This allows the researcher to recheck all data inputs as part of interpretation and drawing conclusions from the data gathered. A study protocol is embedded in this thesis; the procedures, questions, objectives and context of this study are highlighted in Chapters 1 and 3. The steps followed and the outcomes achieved are noted in Chapters 4 and 5. Accuracy of the findings is checked as part of the user assessment process. All of the above contribute to the reliability of this study.

The requirement of generalisation relates to measuring the applicability of the research findings in a broader scope, beyond the boundaries of the specific study (Blaxter *et al.*, 2006; Welman *et al.*, 2005). However, according to Creswell (2013) generalisation is not commonly used in qualitative research or mixed method designs as the intention of this form of research is not to generalise findings to an environment beyond that of the study. This is also the case with this research; it is intended for use in the SA Navy.

6.2 Validation methodology

The purpose of Chapter 6 is to ascertain whether the SANAIDMF has value in aiding decision-making in the SAN, from a theoretical and practical point of view. Ideally, validation should quantify the success of the decision-making framework in its intended environment. Although the researcher has access to the SAN to do such a validation, according to Borenstein (1998) quantitative validation methods typically require a number of tests and controlled data procedures, which are beyond the time constraints of this study. Qualitative-based validation will thus be used, which might seem informal, but, depending on design, can be exceptionally formal (Borenstein, 1998). Creswell (2007) states that in qualitative validation a convergence of evidence is desired to build confidence in the observations, interpretations and conclusions of the study.

For convergence two validation methods are used: Face validation and user assessment. Authoritative sources in the field are used to carry out face validation. The intent with face validation is to ascertain the consistency level between the researcher's view and the intended user's view (Borenstein, 1998). Additionally, Welman *et al.* (2005) states that face validation plays an important role in testing a self-developed instrument. Although face validation is a subjective assessment, it is a time- and cost-effective method to verify the construct validity (Borenstein, 1998). Subjective judgement is required in the research process according to Drost (2011); moreover, because the development of the SANAIDMF relied heavily on expert opinions, and is intended for use exclusively in the SAN environment. The group of subject matter experts who were approached to complete the second questionnaire are identified as prospective participants to perform face validation.

Borenstein (1998) also states that user assessment is a valuable process that determines whether a decision support system can be used in decision making with some level of confidence. However, Borenstein (1998) continues by saying that the parties involved in user assessment should not be part of the origins, development or implementation of the decision support system.

In the case of the SANAIDMF there is a finite number of individuals who have sufficient knowledge and experience to provide data input for the development, as well as assist with validation of the decision-making framework. The possible number of participants is not enough to split the group into those providing input and those validating. Thus, the same participants that provided input by responding to the first questionnaire must be asked follow up questions for purpose of user assessment validation.

This participants in this group are chosen because they have experience in System Management in the SAN. The data gathered from them in the first questionnaire was individual expert opinions, which were combined and incorporated into the decision-making framework. However, the participants were isolated by the researcher from any other development activities of the SANAIDMF. The participants in this group did not form part of the origins, development or implementation of the SANAIDMF. The same group is thus used for user validation.

The survey instrument chosen for validation is a questionnaire. With the limited availability of the experts to form part of a focus group a questionnaire allows flexibility with its completion. It also proved effective with the participants so far in this research. As with the first and second rounds of data collection, appointments are made with the participants during which the questionnaire is explained and also collected after completion.

Open- and closed-ended questions are used. The closed-ended questions ensure that the participant's answer is not influenced by the researcher. Welman *et al.* (2005) state that a varied response, which could be an abundant source of information, is to be expected from open-ended questions.

Closed-ended questions are asked to verify that the success criteria are satisfactorily met. Here a rating scale is used. The number of points in a rating scale is a contentious issue. In this instance it is important to balance the scale, with an equal number of negatives and positives. In addition, a neutral option is required to avoid bias towards the positive when a participant is neutral on the matter. Taylor-Powell (2008) recommends a five-point scale for use with a unipolar scale. Additionally, according to Hossain *et al.* (2014), the five-point scale is more user friendly than the longer ones. A five-point scale is therefore chosen using *Very poor, Poor, Fair, Good* and *Very good* as its points.

The validation questionnaires used are the same, with the perspective of the participants being the differentiating factor. The aim with face validation leans more towards construct validity and user assessment towards content validity. The participants chosen to take part in the user assessment are the envisaged users and they evaluate the SANAIDMF from a user's point of view. The participants chosen to take part in face validation are not users, but rather authoritative individuals (subject matter experts) who are involved in management process design in the SAN with a holistic point of view. Albeit that the overarching objective in terms of Asset Management of both groups is the same, their perspective and day-to-day goals differ significantly. The validation questionnaire is included as Appendix H.

6.3 Success criteria

Success criteria must be defined against which the SANAIDMF can be measured. Davis (1989) performed a study into the criteria for predicting user acceptance of information technology (IT), with the purpose of finding better measures to predict usage. Although the focus was on IT systems, the criteria can be applied to a broader spectrum of systems and frameworks. Scholars have effectively used the success factors described below in conjunction with face validation to validate frameworks in the Asset Management environment (Flynn, 2016; De Villiers, 2018). In this study, the system or application referred to by Davis (1989) should be seen as the SANAIDMF.

According to Davis (1989) individuals will decide to use an application based on whether or not they believe it will help them perform better in their work. This is termed 'perceived usefulness': "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989). Thus, a system is more likely to be used if the user believes that the user-performance relationship is advantageous. It is thus important to ascertain the perceived potential that the SANAIDMF has to fulfil its intended function and be valuable to the user, which is the first success criterion.

'Perceived ease of use' is described by Davis (1989) as the belief of a person that using a particular application would be effort free. Even though a user might find an application useful, it is less likely to be used if it is perceived to be too difficult to operate (Davis, 1989). The perceived benefits must thus outweigh the perceived effort required to use the framework. The second success criterion is then perceived ease of use.

In line with the explanation of a framework in Section 1.5 the third and fourth criteria are 'perceived understandability' and 'perceived practicality'. Because the SANAIDMF is not intended to be a static framework, but rather to be tailored as requirements change or more accurate information become available, it should be 'flexible', which is the fifth success criterion.

The sixth and final success criterion is 'establishing construct validity'. As explained in Section 6.1 construct validity ensures that the method of inquiry measured what was needed to answer the research question and that the results serve a useful purpose. To that end, questions regarding the methodology used in this study and the potential of the SANAIDMF answered by those performing face validation is considered essential to successful validation.

Ultimately, the overall measure of success is establishing if the problem statement is answered and the research objectives achieved with the construction of the SANAIDMF. The success criteria contribute to the overall success.

As a recap, success is achieved when:

1. The SANAIDMF is perceived as useful;
2. The SANAIDMF is perceived as easy to use;
3. The SANAIDMF is perceived as practical ;
4. The SANAIDMF is perceived as understandable;
5. The SANAIDMF is perceived as flexible;
6. Construct validity is established.

Success criteria one to five ensure content validity and success criterion sixth ensures construct validity.

6.4 Expert panel

According to the Department of Sustainability and Environment (2005) expert panels are engaged when specialised opinions are required. Beecham *et al.* (2005) suggest that experts should be drawn from a population of experienced practitioners and researchers in the field in question. An expert in this study is defined as a person who has several years' experience, practical or research based, in the fields of system engineering, system management or logistic engineering in the context of the SA Navy. Although the number of possible participants is small, there are enough individuals to fulfil both the practitioner and researcher requirements for a face validation expert panel. The expert panel used for user validation will only have experts with practical experience, as there are no researchers available who are user experts as well.

Five suitable experts were identified for face validation, three of whom were willing to participate in the study. For brevity a code is assigned to each participant, which will be used from here onwards. The participants are all in the employ of the SA Navy and include:

- a *Chief Engineer(CE)* (PhD): Experience as system engineer, system management process designer, system management course designer and presenter, as well as management consultant. This expert fulfils the requirement of a researcher in the field.
- a *Manager Integrated Logistic Support (MILS)*: Experience in marine engineering, maintenance management software development and implementation, maintenance management and system management. This expert is a practitioner in the field.

- an *Acting Head of Logistic Engineering (AHLE)* (MSc): Experience in system management, financial management and logistic management. This expert is a practitioner in the field.

Another five suitable user experts were identified for user validation, three of whom were willing to participate. These participants include:

- a *System Manager Submarines (SMS)*: 18 years' experience in marine engineering, maintenance management and system management.
- a *System Manager Combat Support Ships (SMCSS)*: 17 years' experience in system management.
- a *System Manager Diving (SMD)*: 9 years' experience in system management.

6.5 Results

As mentioned before the same questionnaire is sent to both panels' experts, the difference being the perspective of each expert when answering the questionnaire. Emphasis is placed on the construct validity questions posed to the face validation panel in order to measure success in the sixth success criterion. The results of the face validation expert panel are thus presented separately for this criterion (see Section 6.5.2). The results of both expert panels for closed-ended questions regarding the perceived usefulness, ease of use, practicality, understandability and flexibility are presented together in Figure 6.1 and discussed in Section 6.5.1.

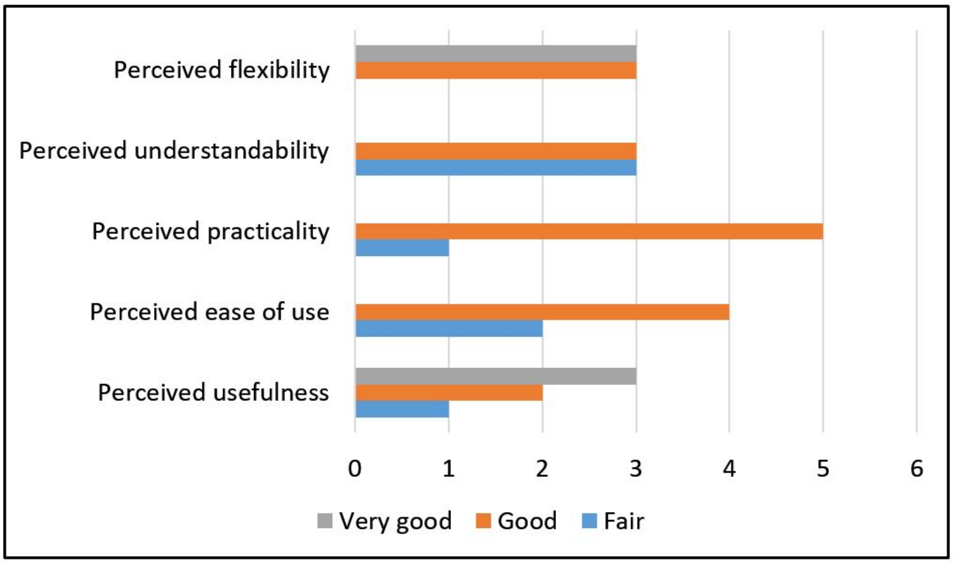


Figure 6.1: Validation questionnaire results: closed-ended questions

6.5.1 Content validity

Overall the SANAIDMF is perceived as useful. Three respondents rated the potential usefulness of the SANAIDMF as *Very good*, two felt it was *Good* and one was neutral. The following comments were added:

- "The potential is good, but the actual AI elements used would probably need to go through a few more iterations" - AHLE
- "At present it seems that the SANAIDMF has been designed for use by the PSM only. Although it could possibly be used to rank the importance of the different AI elements there will be very little action that can be taken by the PSM. Product lead time can be used to illustrate. The lead time is also dependent on the effectiveness of NBS Procurement. They are currently highly ineffective due to manpower shortage and the PSM has no or very little influence over that. What is the point if inventory re-order points are set but there is no funding and we have an ineffective procurement organisation." - SMCSS
- "SMDIV is more of a product manager than a full level 5 Systems Manager and his products are heavily dependant [sic] on the HR Element which he has absolutely no control over" - SMD
- "I feel the tool will aid in assisting the respective system managers in determining priorities within their respective spheres of influence" - SMS

Two users placed emphasis on delineating their responsibility as individual decision-makers, which mismatches the AI elements of the SANAIDMF. The SANAIDMF is, however, not intended to limit the AI elements to only those under direct control of the decision-maker, but rather make the link between the decision taken and any information needed. Whether or not the AI element is under the control of the decision-maker, the information is still required to make decisions and ultimately achieve the required operational availability of systems. The SANAIDMF reveals the link between a particular AI element and operational availability. SMS used the words "spheres of influence" and that is crucial in the opinion of the author. The decision-makers might not always have direct control over all AI elements, but can use their influence and the SANAIDMF, to persuade the parties who are in control of the critical AI elements to take the required action.

Four respondents rated the perceived ease of use of the SANAIDMF as *Good*, with two being neutral. One respondent added: "I feel the concept of using an Excel spreadsheet to facilitate the process is clever. It is a tool that is readily available in the SAN and most system managers will be able to manipulate the tool to obtain the data they require." - SMS. "The strengths of the SANAIDMF are that calculations and formulas are done and it works. I do not agree with the AI elements selected but that could easily be changed" - SMCSS. The statement by SMCSS speaks to user friendliness as well as flexibility.

The perceived practicality is generally rated as *Good*, with only one respondent being neutral. Half of the respondents are neutral, with the other half perceiving the SANAIDMF as understandable. All of the respondents perceived the SANAIDMF to be flexible, with half the scores being *Good* and the other half being *Very good*.

Only one respondent indicated he would not use the SANAIDMF - AHLE. He stated the incorrect mix of AI elements as a reason, but also suggested that more iterations be carried out with the SANAIDMF and that comparative studies be carried out in different industries to assist. By following the suggestions and changing the AI element mix the respondent is likely to change his opinion regarding the use of the SANAIDMF. All other respondents indicated they would use the SANAIDMF if they were in a position to improve Asset Information integrity in the SA Navy. One respondent even said "Definitely" - CE.

Based on the majority of the ratings being positive and a minority neutral (no negative rating was received), it can be concluded that success criteria one to five are achieved.

6.5.2 Construct validity

Achieving construct validity entails determining if the method of inquiry used actually evaluates what was required to answer the research question and if the scores are useful in the research (Creswell, 2013). One respondent said: "It sets a baseline model which can be expanded in future. Good methodology followed" - CE. Another noted that one of the strengths of the SANAIDMF is: "Documenting A_O and laying down a foundation to aid fact based decisions" - MILS.

The third face validation respondent did not comment on the method of inquiry, but rather expressed concerns about what was uncovered in the first round of data collection: "The strengths and weaknesses go hand in hand. It is good that it is based on those managing the AI element. However, for at least the last decade that management has taken place in 'fire-fighting' mode, implying that those who commented on and chose the value/risk/information metrics have themselves not recently operated in a normative environment, meaning that future decisions based on recent previous experience can lead to flawed expectations and outcomes" - AHLE. The other two respondents had similar concerns when commenting on the weaknesses of the SANAIDMF: "Too many identified AI elements in the current model: will have to be reduced somehow. Not sure whether all elements are relevant to A_O - how knowledgeable are respondents with regards to A_O influencers?" - CE and "The current hierarchy of AI is subjective and influenced by the accuracy of available data"- MILS.

The matter in which AI elements were identified in the first round of data collection is discussed in Section 5.4. What is discussed there is reaffirmed by AHLE's statement about the selection of AI elements by managers operating for a lengthy period under severe budget constraints. That was, however, an unexpected outcome of the research: raising the question of where the focus of the decision-makers in the SAN should be when attempting to achieve Operational Availability, given the constraints imposed. Without carrying out this research it would not have been possible to gain empirical evidence of that. No negative comments were received on the SANAIDMF's logic or methods of collecting data, only the outcome of the first iteration. Therefore, using the face validation panel's answers it can be concluded that construct validity for the SANAIDMF is established.

Although it is not considered for construct validity, the answers received from the user validation panel regarding the strengths, weaknesses and methodology followed are included and discussed here for completeness.

"In terms of research objectives I think the right questions were asked but I am not sure about the methodology. The weakness is that there are too many elements. In terms of the methodology, the questionnaire to ascertain which decision are made by a Product System Manager could be based on already researched and validated academic data if it is available. This could possibly be the reason why 66 elements were identified and we are not even sure if important elements were not included. Many of the elements can also be grouped" - SMCSS. There is no academic data available to satisfy the requirement of an AI decision-making framework for the SA Navy. Inferences can be made from AI elements found in literature, but that must still be validated for use in the context of the SA Navy. That is a consideration that could be implemented in future iterations of the SANAIDMF, but for this study the researcher opted to ask open-ended questions instead of leading the participants in terms of choosing AI elements.

As with the discussion in Section 5.4 the philosophical question arises, as to whether decision-makers accept the current situation and operate within the constraints imposed or do they opt for a 'best practices scenario' which might not necessarily cater for the abnormal constraints experienced in the SA Navy? Quantifying trade-offs in 'what-if scenarios' is an area where the SANAIDMF is envisaged to be a particularly useful decision-making tool. This is by creating as many iterations of SANAIDMF as required, which are based on diverse scenarios and asset classes in the SA Navy, whilst refining the database of AI elements and their attributes in the background. Grouping of the AI elements can be done according to each decision-maker's preference when they apply the SANAIDMF to their unique environment or situation.

Another respondent answered: "I think the questions utilised to develop the tool were adequate to demonstrate the tool's functionality. I believe the questions need to be amended though to better reflect the actual questions that are being asked by the system managers" - SMS. The decisions impacting operational availability taken by decision-makers cannot be updated in this study due to time constraints. However, they should definitely be updated in the next iteration of the SANAIDMF.

6.5.3 Improvement suggestions

A question posed to the respondents was what they would improve in the SANAIDMF. Two responded answered that improvements should be made based on feedback when using the framework. "Improvements based on utilisation of the framework" - MILS and "Use the framework practically for a specified time, to evaluate performance in a practical manner" - SMD. This is seen as an essential improvement aspect. Although the SANAIDMF is perceived as easy to use, flexible, understandable, practical and useful only practically applying it will verify that. Time constraints of this study unfortunately do not allow for this to take place.

"AI elements must be revised and reduced. Some of the elements can be grouped under one heading. Many of the elements such as 'maintenance task information' and 'minimum stock levels' are part of an OSBL. Only AI elements that can be directly influenced by the PSM must be listed. The SANAIDMF must then be designed for each section within FLD as well as each directorate within Fleet command to ensure an integrated SANAIDMF. The Capability Manager is crucial in this process. Consider designing the SANAIDMF to the support of the OSBL. The support of each ESWBS element can be measured in terms of information available per ILS element. This will produce a matrix of information that can be used as input to the SANAIDMF to assist the PSM in prioritising work" - SMCSS.

Grouping of the AI elements, specifically those that are part of an umbrella term such as OSBL, was discussed in Sections 4.2 and 4.3. At the time, considering that numerous decision-makers' inputs were considered, that was the maximum grouping that could take place without discounting research content. Each decision-maker has different requirements and can group AI elements in future iterations of the SANAIDMF to be applicable to their unique environment. The influence and direct control of system managers on AI elements were discussed in Section 6.5.1. The other improvement suggestions made by SMCSS, although valid, falls outside the scope of this study. Future research can be undertaken in these areas.

"I think the explanation of how the tool is used needs to be expanded. The explanation needs to be simplified so that anyone opening the tool will be able to utilise it." This suggestion can be implemented in this study. The explanation in Excel format of the SANAIDMF is updated from what was sent out with the validation questionnaire.

"Similar studies should be conducted in for example Transnet and at SAA, or the Airforce, and the results compared and refined in iterative improvements of the SANAIDMF" - AHLE. These improvement suggestions are valid, but also fall outside the scope of this study. Comparative studies will require research projects of their own and could be done in future research.

6.6 Chapter conclusion

This chapter started with a discussion on validity and the validation methodology used in this research. Subsequently success criteria were set and the expert panel discussed. The results of the validation process were then presented, showing that the research has been successfully validated. Improvement suggestions received from the expert panel were also discussed, and implemented where possible within the limitations of this study.

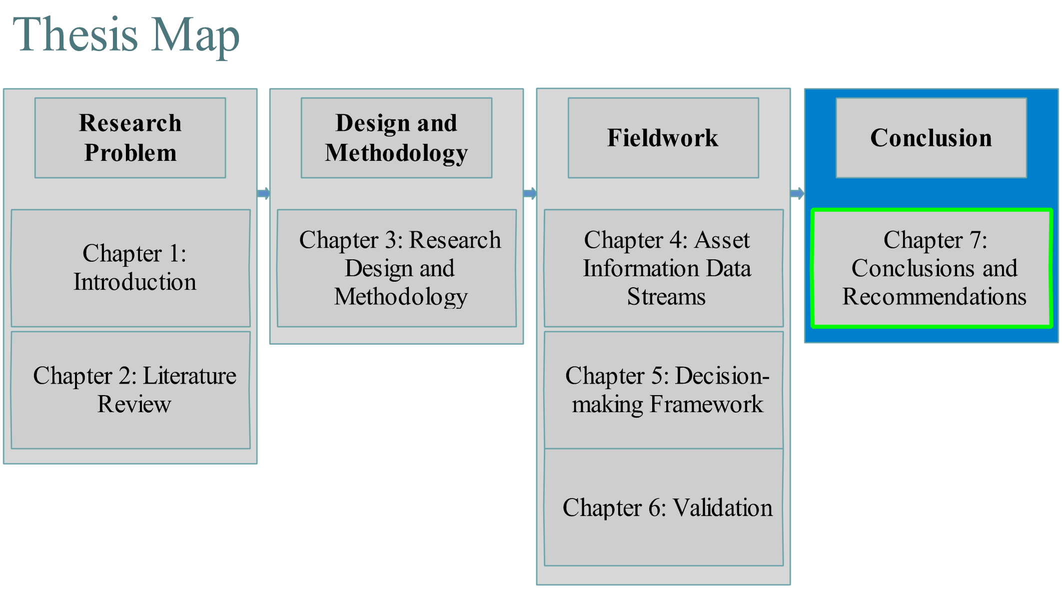
The eighth and last research sub-objective of validating the SANAIDMF was achieved in this chapter. Be achieving all the sub-objectives and answering the secondary research question the primary research question is also answered.

Chapter 7

Conclusions and recommendations

”When you can measure what you are speaking about, and can express it in numbers, you know something about it…otherwise your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of science”

– Lord Kelvin (William Thomson, 1824-1907)



7.1 Summary of work

The study originates from the need to understand the influence of AI within the SAN's AM system in order to aid decision-making. A link was formed between operational availability and achieving the mandated core outputs of the SAN by reviewing literature. The study then set out to quantify the effect of AI on the operation availability of the SAN's system, also taking into consideration the costs and risks involved with each AI element. It proposes a framework that ranks AI elements in order of preference as determined by decision-makers. Data collected from experts is used to develop the framework.

Chapter 1 provides an introduction to the research by discussing the background and context before stating the research problem. Based on the research problem the following research questions are posed:

1. *Primary:* Can an asset information decision-making framework be constructed for the SAN?
2. *Secondary:*
    a) What critical decisions affecting operational availability of systems in the SAN are taken that required AI as input?
    b) What are the AI data streams that support critical decision-making affecting operational availability in the SAN?
    c) How can a framework be constructed to understand the impact of each of the AI elements on operational availability?

Research objectives required to answer the research questions follow which lead to an overview of the research design and methodology. The delimitations and limitations of the study are presented as well as a thesis outline.

Chapter 2 serves as the theoretical foundation for the research by reviewing literature relevant to the study. It starts off by exploring AM in detail: its origins, definitions, fundamentals and AM systems. Next, literature regarding the context of the SAN as well as AM and AI in the SAN is reviewed. Thirdly, systems engineering theory is reviewed due to the DOD's system approach to management of assets. Lastly, literature is provided on decision-making, focussing on various MCDM methods.

In *Chapter 3* the research approach, design and methodology are detailed. A philosophical world-view of pragmatism is what this thesis is based upon as it is well suited for the chosen exploratory mixed method research design. The pragmatic world-view allows the researcher freedom to use multiple methods, assumptions, forms of data collection and analysis techniques. The two phases of data collection are outlined during which data collection, analysis and ethical considerations are detailed.

Chapter 4 describes the qualitative phase of the research. The first round of data collection, making use of a survey based questionnaire, is discussed before the data is analysed. The findings of the first phase results are discussed before the chapter is concluded.

Chapter 5 is where the quantitative phase of the research is presented. Before the data collection a preliminary framework is developed based on AHP-MAUT principles and the data collected in the first phase. This preliminary framework is used as the questionnaire for the second round data collection. The data collected is analysed and it then forms part of the SANAIDMF. The results of the research are deliberated before the chapter conclusion.

The aim of *Chapter 6* is to validate the SANAIDMF. Validation methodology is discussed before success criteria are identified. An expert panel is used to carry out face validation and user validation. The results of the validation questionnaire, based on the success criteria, are presented. Improvement suggestions from the expert panel are discussed, and implemented where possible.

7.2 Conclusions

Knowledge is the basis for decision making (IAM, 2014). Therefore the correct information, at the right time and in the right format must be available to make productive decisions. There is a link between the core outputs of the SA Navy and the operational availability of its weapon systems. To achieve the required operational availability, decision-makers in the SAN must make the correct decisions, with the aid of the correct information. Incorrect, or a lack of information, increases the risk of not achieving the required operational availability.

There is literature that describes AI in detail, but it does not quantify the effect it has on operational availability, especially not in the context of the SA Navy. AI costs money to gather and maintain and in the current economic climate of the SA Navy some areas will be neglected. It is crucial that neither critical areas nor areas with an advantageous cost-benefit relationship be neglected. In the absence of such information this study proposes a dynamic decision-making framework that quantifies the cost-benefit-risk relationship of AI elements in relation to achieving operational outcomes for the SA Navy.

To develop an asset information decision-making framework for the SA Navy certain sub-objectives were set. *Sub-objective 1 - Establish the funda-*

mentals in the relevant fields of study with a literature review was addressed in Chapter 2. *Sub-objective 2 - Construct a well-grounded research methodology* is achieved in Chapter 3 by detailing the research approach, design and methodology of this thesis.

In Chapter 4 *sub-objective 3 - Identify critical AI based decisions taken in the SAN that has an influence on system operational availability* and *sub-objective 4 - Establish data streams required for decision making* are achieved. This is done by using a top-down approach, asking participants in a survey which decisions they would take that they feel would have an effect on the operational availability of SAN systems; as well as what information is required by them to make their stated decision. This answers *research questions 1 and 2 - What critical decisions affecting operational availability of systems in the SAN are taken that required AI as input?* and *What are the AI data streams that support critical decision making affecting operational availability in the SAN?*. This concludes the qualitative phase of the study and forms the base for the quantitative phase of the study.

In Chapter 5 after MCDM methods were compared it was decided to base the algorithm of the framework on a AHP-MAUT hybrid approach. Combining the algorithm and data collected in the first phase a preliminary decision-making framework was developed. That satisfied *sub-objective 5 - Construct a preliminary framework*. The preliminary framework was used in a questionnaire where subject matter experts were firstly asked to provide preference ratios for the selected criteria. Secondly the subject matter expert were asked to score the attributes of each AI element identified in the first phase data collection. This satisfied *sub-objective 6 - Determine the influence of AI elements on the SAN's operational availability*.

Sub-objective 7 - Consolidate the preliminary framework and the influence of AI on decisions into the South African Navy Asset Information Decision Making Framework (SANAIDMF) was also achieved in Chapter 5. Chapter 6 concentrated on validating the SANAIDMF and meeting *sub-objective 8 - Validate the SANAIDMF*. An expert panel was used to carry out face validation and user validation. The list of AI elements as per the outcome of the first phase data collection attracted many comments from the expert panel, almost overshadowing the rest of the SANAIDMF. *Research question 3 - How can a framework be constructed to understand the impact of each of the AI elements on operational availability?* is addressed in Chapters 5 and 6.

Although the ranked list of elements presented in this iteration of the SANAIDMF are contentious and more iterations are required with different input data, the research objectives and validation success criteria were met.

7.3 Recommendations for further research

During the study, areas for future research were identified, either from opportunities for improvement, from the limitations imposed on this research or from feedback during the validation process. The following suggestions could add value or contribute to this research:

- Comparative studies could be performed in similar industries. By comparing results iterative improvements and refinement of the SANAIDMF can take place.
- This study took a survey across all asset classes of the SA Navy and did not consider the focus of the decision makers. More iterations of the same study could be performed in the SA Navy, concentrating on varying the focus of decision-makers and selecting specific asset classes.
- The SANAIDMF was not implemented to determine its validity due to time constraints in this study. It is recommended that the SANAIDMF be implemented to be validated in the field. This will also identify difficulties with implementation and derive improvements to be made.
- According to expert input it would be valuable if the SANAIDMF would be implemented at various directorates in the SA Navy, to ensure an integrated framework. This goes hand in hand with the recommendation for more iterations of the same study.

7.4 Contributions to industry

In its current form the SANAIDMF is only of value to the SA Navy. In the SA Navy it can be used to increase the value for money relationship by identifying priorities.

It could be applied to other industries, but that would require another study to determine their data needs and associated costs and risks. It is however to the benefit of the AM field in general as, according to one expert, it sets a baseline model which can be expanded in future studies.

7.5 Chapter conclusion

This chapter concludes the research. A summary of the work carried out is given before concluding remarks are provided on the achievement of the research objectives and validation. After review it is concluded that the research objectives as per Section 1.3 are successfully achieved. Recommendations for further research are made and the contributions to industry described.

Appendices

Appendix A

Survey research approval

A phased approach is followed in this research, with the questionnaire of the second phase dependent on information obtained in the first phase (see Chapter 3 for more detail). Therefore two applications were submitted to the Research and Ethics Committee (REC) for approval, both of which are approved and included in this appendix.

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APPROVED WITH STIPULATIONS
REC Humanities New Application Form

30 August 2018

Project number: ING-2018-7845

Project title: Physical Asset Information Integrity and Associated Risks: Case study of the South African Navy

Dear Mr Christian Fourie

Your REC Humanities New Application Form submitted on **10 August 2018** was reviewed by the REC: Humanities on and approved with stipulations.

Ethics approval period:

Protocol approval date (Humanities)	Protocol expiration date (Humanities)
30 August 2018	29 August 2021

REC STIPULATIONS:

The researcher may proceed with the envisaged research provided that the following stipulations, relevant to the approval of the project are adhered to or addressed:

1) The researcher intends on conducting a phased approach, once phase one is complete, he may only begin with phase two once the data collection methods have been attached to his online application. **[ACTION REQUIRED]**

2) The Permission Letter is dated June 2016, the researcher should confirm in writing if the Permission is still valid and attach the correspondence to his online application. If the Permission is no longer valid, an updated Permission Letter needs to be attached. **[ACTION REQUIRED]**

The researcher should only respond once all the required documents are in place.

HOW TO RESPOND:

Some of these stipulations may require your response. Where a response is required, you must respond to the REC within **six (6)** months of the date of this letter. Your approval would expire automatically should your response not be received by the REC within 6 months of the date of this letter.

Your response (and all changes requested) must be done directly on the electronic application form on the Infonetica system: https://applyethics.sun.ac.za/Project/Index/10353

Where revision to supporting documents is required, please ensure that you replace all outdated documents on your application form with the revised versions. Please respond to the stipulations in a separate cover letter titled "**Response to REC stipulations**" and attach the cover letter in the section **Additional Information and Documents**.

Please take note of the General Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

If the researcher deviates in any way from the proposal approved by the REC: Humanities, the researcher must notify the REC of these changes.

Please use your SU project number **(7845)** on any documents or correspondence with the REC concerning your project.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

FOR CONTINUATION OF PROJECTS AFTER REC APPROVAL PERIOD

Please note that a progress report should be submitted to the Research Ethics Committee: Humanities before the approval period has expired if a continuation of ethics approval is required. The Committee will then consider the continuation of the project for a further year (if necessary)

Included Documents:

Document Type	File Name	Date	Version
Proof of permission	Authority for studies - Intelligence	24/07/2018	1
Informed Consent Form	Consent form	24/07/2018	1
Research Protocol/Proposal	Research Proposal-Thesis	09/08/2018	2
Data collection tool	Questionnaire	09/08/2018	2

If you have any questions or need further help, please contact the REC office at cgraham@sun.ac.za.

Sincerely,

Clarissa Graham

REC Coordinator: Research Ethics Committee: Human Research (Humanities)

National Health Research Ethics Committee (NHREC) registration number: REC-050411-032. The Research Ethics Committee: Humanities complies with the SA National Health Act No.61 2003 as it pertains to health research. In addition, this committee abides by the ethical norms and principles for research established by the Declaration of Helsinki (2013) and the Department of Health Guidelines for Ethical Research: Principles Structures and Processes (2nd Ed.) 2015. Annually a number of projects may be selected randomly for an external audit.

Investigator Responsibilities

Protection of Human Research Participants

Some of the general responsibilities investigators have when conducting research involving human participants are listed below:

1. Conducting the Research. You are responsible for making sure that the research is conducted according to the REC approved research protocol. You are also responsible for the actions of all your co-investigators and research staff involved with this research. You must also ensure that the research is conducted within the standards of your field of research.

2.Participant Enrollment. You may not recruit or enrol participants prior to the REC approval date or after the expiration date of REC approval. All recruitment materials for any form of media must be approved by the REC prior to their use.

3.Informed Consent. You are responsible for obtaining and documenting effective informed consent using **only** the REC-approved consent documents/process, and for ensuring that no human participants are involved in research prior to obtaining their informed consent. Please give all participants copies of the signed informed consent documents. Keep the originals in your secured research files for at least five (5) years.

4.Continuing Review. The REC must review and approve all REC-approved research proposals at intervals appropriate to the degree of risk but not less than once per year. There is **no grace period.** Prior to the date on which the REC approval of the research expires, **it is your responsibility to submit the progress report in a timely fashion to ensure a lapse in REC approval does not occur.** If REC approval of your research lapses, you must stop new participant enrollment, and contact the REC office immediately.

5.Amendments and Changes. If you wish to amend or change any aspect of your research (such as research design, interventions or procedures, participant population, informed consent document, instruments, surveys or recruiting material), you must submit the amendment to the REC for review using the current Amendment Form. You **may not initiate** any amendments or changes to your research without first obtaining written REC review and approval. The **only exception** is when it is necessary to eliminate apparent immediate hazards to participants and the REC should be immediately informed of this necessity.

6.Adverse or Unanticipated Events. Any serious adverse events, participant complaints, and all unanticipated problems that involve risks to participants or others, as well as any research-related injuries, occurring at this institution or at other performance sites must be reported to Malene Fouche within **five (5) days** of discovery of the incident. You must also report any instances of serious or continuing problems, or non-compliance with the RECs requirements for protecting human research participants. The only exception to this policy is that the death of a research participant must be reported in accordance with the Stellenbosch University Research Ethics Committee Standard Operating Procedures. All reportable events should be submitted to the REC using the Serious Adverse Event Report Form.

7.Research Record Keeping. You must keep the following research-related records, at a minimum, in a secure location for a minimum of five years: the REC approved research proposal and all amendments; all informed consent documents; recruiting materials; continuing review reports; adverse or unanticipated events; and all correspondence from the REC

8.Provision of Counselling or emergency support. When a dedicated counsellor or psychologist provides support to a participant without prior REC review and approval, to the extent permitted by law, such activities will not be recognised as research nor the data used in support of research. Such cases should be indicated in the progress report or final report.

9.Final reports. When you have completed (no further participant enrollment, interactions or interventions) or stopped work on your research, you must submit a Final Report to the REC.

10.On-Site Evaluations, Inspections, or Audits. If you are notified that your research will be reviewed or audited by the sponsor or any other external agency or any internal group, you must inform the REC immediately of the impending audit/evaluation.

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NOTICE OF APPROVAL

REC: Social, Behavioural and Education Research (SBER) - Initial Application Form

16 August 2019

Project number: 7845

Project Title: Physical Asset Information Integrity and Associated Risks: Case study of the South African Navy

Dear Mr Christian Fourie

Your REC: Social, Behavioural and Education Research (SBER) - Initial Application Form submitted on **28 July 2019** was reviewed and approved by the REC: Humanities.

Please note the following for your approved submission:

Ethics approval period:

Protocol approval date (Humanities)	Protocol expiration date (Humanities)
30 August 2018	29 August 2021

GENERAL COMMENTS:

Please take note of the General Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

If the researcher deviates in any way from the proposal approved by the REC: Humanities, the researcher must notify the REC of these changes.

Please use your **SU project number (7845)** on any documents or correspondence with the REC concerning your project.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

FOR CONTINUATION OF PROJECTS AFTER REC APPROVAL PERIOD

Please note that a progress report should be submitted to the Research Ethics Committee: Humanities before the approval period has expired if a continuation of ethics approval is required. The Committee will then consider the continuation of the project for a further year (if necessary)

Included Documents:

Document Type	File Name	Date	Version
Proof of permission	Authority for studies - Intelligence	24/07/2018	1
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Research Protocol/Proposal	Research Proposal-Thesis	09/08/2018	2
Data collection tool	Questionnaire	09/08/2018	2
Informed Consent Form	2nd Round Consent form	24/07/2019	1
Data collection tool	2nd Round Questionnaire	24/07/2019	1
Proof of permission	Authority and Letter confirming permission validity	24/07/2019	1

If you have any questions or need further help, please contact the REC office at cgraham@sun.ac.za.

Sincerely,

Clarissa Graham

REC Coordinator: Research Ethics Committee: Human Research (Humanities)

National Health Research Ethics Committee (NHREC) registration number: REC-050411-032.
The Research Ethics Committee: Humanities complies with the SA National Health Act No.61 2003 as it pertains to health research. In addition, this committee abides by the ethical norms and principles for research established by the Declaration of Helsinki (2013) and the Department of Health Guidelines for Ethical Research: Principles Structures and Processes (2nd Ed.) 2015. *Annually a number of projects may be selected randomly for an external audit.*

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2.Participant Enrollment. You may not recruit or enroll participants prior to the REC approval date or after the expiration date of REC approval. All recruitment materials for any form of media must be approved by the REC prior to their use.

3.Informed Consent. You are responsible for obtaining and documenting effective informed consent using **only** the REC-approved consent documents/process, and for ensuring that no human participants are involved in research prior to obtaining their informed consent. Please give all participants copies of the signed informed consent documents. Keep the originals in your secured research files for at least five (5) years.

4.Continuing Review. The REC must review and approve all REC-approved research proposals at intervals appropriate to the degree of risk but not less than once per year. There is **no grace period.** Prior to the date on which the REC approval of the research expires, **it is your responsibility to submit the progress report in a timely fashion to ensure a lapse in REC approval does not occur.** If REC approval of your research lapses, you must stop new participant enrollment, and contact the REC office immediately.

5.Amendments and Changes. If you wish to amend or change any aspect of your research (such as research design, interventions or procedures, participant population, informed consent document, instruments, surveys or recruiting material), you must submit the amendment to the REC for review using the current Amendment Form. You **may not initiate** any amendments or changes to your research without first obtaining written REC review and approval. The **only exception** is when it is necessary to eliminate apparent immediate hazards to participants and the REC should be immediately informed of this necessity.

6.Adverse or Unanticipated Events. Any serious adverse events, participant complaints, and all unanticipated problems that involve risks to participants or others, as well as any research related injuries, occurring at this institution or at other performance sites must be reported to Malene Fouche within **five (5) days** of discovery of the incident. You must also report any instances of serious or continuing problems, or non-compliance with the RECs requirements for protecting human research participants. The only exception to this policy is that the death of a research participant must be reported in accordance with the Stellenbosch University Research Ethics Committee Standard Operating Procedures. All reportable events should be submitted to the REC using the Serious Adverse Event Report Form.

7.Research Record Keeping. You must keep the following research related records, at a minimum, in a secure location for a minimum of five years: the REC approved research proposal and all amendments; all informed consent documents; recruiting materials; continuing review reports; adverse or unanticipated events; and all correspondence from the REC

8.Provision of Counselling or emergency support. When a dedicated counsellor or psychologist provides support to a participant without prior REC review and approval, to the extent permitted by law, such activities will not be recognised as research nor the data used in support of research. Such cases should be indicated in the progress report or final report.

9.Final reports. When you have completed (no further participant enrollment, interactions or interventions) or stopped work on your research, you must submit a Final Report to the REC.

10.On-Site Evaluations, Inspections, or Audits. If you are notified that your research will be reviewed or audited by the sponsor or any other external agency or any internal group, you must inform the REC immediately of the impending audit/evaluation.

Appendix B

First survey

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jou kennisvennoot • your knowledge partner

STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

You are invited to take part in a study conducted by Christian Fourie (M.Eng student), from the Department of Industrial Engineering at Stellenbosch University. The results of the research will contribute to Christian's M.Eng thesis. You were approached as a possible participant because of your knowledge of asset management or the management structures of the South African Navy (SAN).

1. PURPOSE OF THE STUDY

The study is in the field of asset management (AM) and aims to build a framework for understanding the effect of asset information on the core outputs of the SAN. The availability and reliability of assets are measureable concepts that are linked to the core outputs of the SAN. The outputs being: 1) Conducting ordered defence commitments in accordance with government policy and strategy (measured by the number of hours at sea per year), and 2) providing mission ready defence capabilities (measured by the percentage compliance with joint force employment requirements). Both outputs can be related to operational availability (A_O)

The study takes a top down approach in the first phase, starting by ascertaining which decisions are made using asset information that affect A_O. These decisions needs to impact on the availability of military systems as the main aim is to quantify the impact of Asset Information on core outputs. Data streams are then build by the researcher after which phase two commences. During this phase decision support modelling will be used to ultimately assign a relative weight of importance to Asset Information elements. This will then provide an indication of the importance of individual data elements in achieving core outputs.

2. WHAT WILL BE ASKED OF ME?

If you agree to take part in this study, you will be asked to complete and sign this consent form. After you indicated your willingness to participate, you will receive the phase 1 questionnaire. Specific instructions will be included in the questionnaire.

The amount of time necessary for completion of the questionnaire will vary with each participant, but should range between 15-20 minutes. There are no right or wrong answers, this study is seeking your expert opinion.

3. POSSIBLE RISKS AND DISCOMFORTS

The only risk to this study is related to the protection of classified information. It is however not foreseen that operational data will be divulged as the focus of the study is on management processes. Approval for the study has been granted by the Department of Defence Chief Director Counter Intelligence. If you however feel that any information you provide are of sensitive nature you can contact the researcher and measures can be put in place to protect the information. The two options are to either disguise details by applying a coding system only available to the researcher e.g. Asset Type A, Asset Type B; or classifying the whole thesis to ensure it is not seen in the public domain.

Should you have any complaints or difficulties with the study you can also contact the researcher at the contact details provided in section 8.

4. POSSIBLE BENEFITS TO PARTICIPANTS AND/OR TO THE SOCIETY

The study might not benefit you as an individual, but the information obtained might contribute to improve the understanding and future research for asset information in the asset management field. It might also benefit the SAN in the future management of assets.

5. PAYMENT FOR PARTICIPATION

You will receive no payment for your participation.

6. PROTECTION OF YOUR INFORMATION, CONFIDENTIALITY AND IDENTITY

Any information you share with me during this study that could possibly identify you as a participant will be protected. This will be done by allocating a unique code to you that is only available to the researcher. You will remain anonymous to other participants throughout the study and only the researcher will be able to identify your specific answers.

The information collected will only be used for this study. The results of the study will be published as part of Christian's M.Eng thesis.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you agree to take part in this study, you may withdraw at any time without any consequence and may choose to have the information you provided removed. You may also refuse to answer any questions you don't want to answer and still remain in the study. The researcher may withdraw you from this study if circumstances arise which warrant doing so.

8. RESEARCHERS' CONTACT INFORMATION

If you have any questions or concerns about this study, please feel free to contact the primary researcher, Christian Fourie (christian.fourie@gmail.com; 061 515 2625) and/or the supervisor Dr J.L. Jooste (wyhan@sun.ac.za; 021 808 4234).

9. RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

DECLARATION OF CONSENT BY THE PARTICIPANT

As the participant I confirm that:

- I have read the above information and it is written in a language that I am comfortable with.
- I have had a chance to ask questions and all my questions have been answered.
- All issues related to privacy, and the confidentiality and use of the information I provide, have been explained.

By signing below, I _______________________________ *(name of participant)* agree to take part in this research study, as conducted by Christian Fourie.

____ ______________________

Signature of Participant **Date**

DECLARATION BY THE PRINCIPAL INVESTIGATOR

As the **principal investigator,** I hereby declare that the information contained in this document has been thoroughly explained to the participant. I also declare that the participant has been encouraged (and has been given ample time) to ask any questions. In addition I would like to select the following option:

	The conversation with the participant was conducted in a language in which the participant is fluent.
	The conversation with the participant was conducted with the assistance of a translator (who has signed a non-disclosure agreement), and this "Consent Form" is available to the participant in a language in which the participant is fluent.

____ ______________________

Signature of Principal Investigator **Date**

Questionnaire

Background

Asset information (AI) is present and important in all life cycle stages of South African Navy (SAN) systems. In the acquisition life cycle stage the focus in terms of AI is on ensuring that the functional and logistic requirements are reflected in the engineering data. During the operational deployment and maintenance life cycle stage the data and information is used to maintain and operate the system. Data identification, structuring, capturing, processing, analysis, reporting, safekeeping, backup and archiving, the whole process of turning data into information and insight for decision support within the SAN must be managed.

As part of the handover between the acquisition phase to the operational deployment and maintenance phase the applicable operational support base line (OSBL) data is transferred to the operational support information system (OSIS). OSIS as an information system is designed to maintain transactional data and does not replace the data management process, it only contains configuration, maintenance and material supply management modules. OSIS will however support the data management process by capturing and manipulating data to provide information to the product system manager (PSM), which can be used to make decisions.

When the OSBL is qualified it is being done with simulated models, whereas the actual physical system is operationally tested. During the operational deployment and maintenance phase the OSBL and resultant data generated, is required to support the system in actual conditions, not simulated models. It could be argued that the initial stages of the operational support and maintenance phase is the operational test for the OSBL. Shortcomings in OSBL data affecting performance of the system, more specifically information requirements enabling asset related decision making, must be continuously monitored and corrected to sustain system readiness objectives i.e. operational availability (A_O). AM in the DOD is making the best life cycle decisions and must support the higher order system plans of the DOD's strategic objectives.

The intention with the study is to uncover the role of specific AI elements in achieving A_O. A top down approach is followed, first establishing the important decisions that is made using AI after which decision support modelling will be used to quantify the impact of each AI element identified during this phase.

Survey

It is important that you answer the questions based on your experience with system management or the management structures of the SAN. There are no right or wrong answers, the study is seeking your expert opinion.
Answers can be written on the survey form, or typed out on additional pages if required. Please complete the survey within *2 weeks* of receiving the questionnaire.

Given the above background, please answer the following questions.

1. In your opinion, which decisions are made that affect the *availability* of systems in the South African Navy (SAN)?
   (List only those that have a noteworthy effect)

2. To make each decision, what information is required?

(Answers to question 2 continued)

(Answers to question 2 continued)

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Demographic information

Please supply the following information

Name: ____

Position: ____

Primary responsibilities: ____

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Years experience in your field: ____

Appendix C

First survey results

Table C.1: Information requirements for decisions one to two

Decision	Budgetary decisions	Re-supply of spares related decisions
Information required	• Qualified OSBL • Spares required per maintenance task • Target inventory levels • Inventory re–order points • Minimum stock levels • Supply lead times • Turnover amount of stock • Pricing • Supplier data • Current stock levels • Spares used per time period • Number of systems required to be online in a given period • Divisions between mission critical spares and all planned spares • Readiness level required • Costing of services required • Historical cost data	• Accurate job–card feedback • Accurate costing of spares and materials • Approved budget • Number of each type of spares to be used in maintenance and other support activities • Inventory levels • Upcoming maintenance requirements • Required delivery schedules • Current stock usage • Predicted stock usage for planned activities • Failure rate data • LSA data • Data showing the difference between predicted hours and material vs actual hours and material used per standard maintenance task

Table C.2: Information requirements for decisions two to five

Decision	**Obsolescence related decisions**	**Unscheduled repair related decisions**	**Scheduled maintenance related decisions**
Information required	• Continuous update of spares availability and funding • Information on alternatives available in the market • Information on systems being operated in other military environments • Financial resources • Product lead time • OEM manufacturing and support information • LSA data	• Information on the availability of skills and special tools at the relevant maintenance level • Historical maintenance data • Information on what proportion of repairs are likely to take place at each level of maintenance • Spares requirements per maintenance level • LSAR data • Current stock levels • Expiration dates of stock in depot	• Number of products requiring scheduled maintenance • Maintenance history • Inventory levels of serviceable items • Maintenance task information • Equipment required for maintenance • Spares required for scheduled maintenance • LSAR data • Information on the availability of skills and special tools at the relevant maintenance level • Current stock usage • Failure rate data • Accurate cost of items • Accurate job–card feedback • Data showing the difference between predicted hours and material vs actual hours and material used per standard maintenance task

Table C.3: Information requirements for decisions six to ten

Decision	**Level of ambition decisions**	**Re-supply of mission related products decisions**	**Movement of maintenance periods due to operational requirements related decisions**	**Movement of key maintenance personnel due to operational requirements related decisions**	**Cannibalizing vessels to meet operational requirements related decisions**
Information required	• Projected missions • Projected equipment priorities • What if scenario's and strategies related to reducing the number of available systems, maintenance of sub-systems, changing maintenance philosophy and changing training policies	• Number of each type of mission related products to be re–supplied • Inventory levels of serviceable items • Consumable products allowance lists • Required delivery schedule • Current stock usage • Predicted stock usage for planned activities • Failure rate data • LSA data • Accurate cost of items • Accurate job–card feedback • Data showing the difference between predicted hours and material vs actual hours and material used per standard maintenance task	• Strategies to reduce readiness and usage levels to ease the utilization of equipment • Period by which the maintenance downtime will be extended to catch up on maintenance once the product system is no longer operationally required • Capacity of repair sections to conduct outstanding maintenance • Studies on the long term effect of delaying maintenance on the product system	• Human resource strategies and plans to replace maintenance personnel with suitably qualified stand–in personnel • Handover procedures (record keeping) • Human resource personnel shortage prevention measure strategies	• Materiel and usage accounting • Studies detailing the overall effect on operational availability if some sub–systems are being used more than originally planned • Equipment sensitivity towards number of uninstall and install procedures

Table C.4: Information requirements for decisions eleven to sixteen

Decision	**Changing the roles of vessels beyond designed roles as well as equipment life extension related decisions**	**Engineering change related decisions**	**Spares refurbishment related decisions**	**New mission related equipment procurement related decisions**	**Execution of planned activities related decisions (daily management)**
Information required	• Allowances of original design parameters such as weight increase, load increase, usage increase as well as structural strength and integrity. • Design change impact studies	• Number of products likely to require modifications • Maintenance history • Modification instructions • Equipment required • Spares required	• Number of candidates for refurbishment • Work to be performed • Equipment and spares required • Previous refurbishment details • Inventory levels of serviceable items • Maintenance history • Usage history	• Number of mission related products to be procured • Supplier production planning • Capital budget information • Industry support contract information • Original product system acquisition plan	• Unplanned breakdown information • Budget information
Decision	**Additional in–house maintenance support and training related decisions**				
Information required	• Status of training facilities • Status of training material and training aids				

Appendix D

Second survey

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

You are invited to take part in a study conducted by Christian Fourie (M.Eng student), from the Department of Industrial Engineering at Stellenbosch University. The results of the research will contribute to Christian's M.Eng thesis. You were approached as a possible participant because of your knowledge of asset management or the management structures of the South African Navy (SAN).

1. PURPOSE OF THE STUDY

The study is in the field of asset management (AM) and aims to build a framework for understanding the effect of asset information on the core outputs of the SAN. The availability and reliability of assets are measureable concepts that are linked to the core outputs of the SAN. The outputs being: 1) Conducting ordered defence commitments in accordance with government policy and strategy (measured by the number of hours at sea per year), and 2) providing mission ready defence capabilities (measured by the percentage compliance with joint force employment requirements). Both outputs can be related to operational availability (A_O).

The study takes a top down approach in the first phase, starting by ascertaining which decisions are made using asset information that affect A_O. These decisions need to impact on the availability of military systems as the main aim is to quantify the impact of Asset Information on core outputs. The results of the first phase are used in a Multi Attribute Utility Theory based questionnaire. During this phase the decision support modelling is used to ultimately assign a relative weight of importance of the Asset Information elements identified in the first phase. This then provides an indication of the importance of individual data elements in achieving core outputs.

2. WHAT WILL BE ASKED OF ME?

If you agree to take part in this study, you will be asked to complete and sign this consent form. After you indicated your willingness to participate, you will receive the phase 2 questionnaire. Specific instructions will be included in the questionnaire.

The amount of time necessary for completion of the questionnaire should range between 30-40 minutes. There are no right or wrong answers, this study is seeking your expert opinion.

3. POSSIBLE RISKS AND DISCOMFORTS

The only risk to this study is related to the protection of classified information. It is however not foreseen that operational data will be divulged as the focus of the study is on management processes. Approval for the study has been granted by the Department of Defence Chief Director Counter Intelligence. If you however feel that any information you provide are of sensitive nature you can contact the researcher and measures can be put in place to protect the information. The two options are to either disguise details by applying a coding system only available to the researcher e.g. Asset Type A, Asset Type B; or classifying the whole thesis to ensure it is not seen in the public domain.

Should you have any complaints or difficulties with the study you can also contact the researcher at the contact details provided in section 8.

4. POSSIBLE BENEFITS TO PARTICIPANTS AND/OR TO THE SOCIETY

The study might not benefit you as an individual, but the information obtained might contribute to improve the understanding and future research for asset information in the asset management field. It might also benefit the SAN in the future management of assets.

5. PAYMENT FOR PARTICIPATION

You will receive no payment for your participation.

6. PROTECTION OF YOUR INFORMATION, CONFIDENTIALITY AND IDENTITY

Any information you share with me during this study that could possibly identify you as a participant will be protected. This will be done by allocating a unique code to you that is only available to the researcher. You will remain anonymous to other participants throughout the study and only the researcher will be able to identify your specific answers.

The information collected will only be used for this study. The results of the study will be published as part of Christian's M.Eng thesis.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you agree to take part in this study, you may withdraw at any time without any consequence and may choose to have the information you provided removed. You may also refuse to answer any questions you don't want to answer and still remain in the study. The researcher may withdraw you from this study if circumstances arise which warrant doing so.

8. RESEARCHERS' CONTACT INFORMATION

If you have any questions or concerns about this study, please feel free to contact the primary researcher, Christian Fourie (christian.fourie@gmail.com; 061 515 2625) and/or the supervisor Dr J.L. Jooste (wyhan@sun.ac.za; 021 808 4234).

9. RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research participant, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

DECLARATION OF CONSENT BY THE PARTICIPANT

As the participant I confirm that:

- I have read the above information and it is written in a language that I am comfortable with.
- I have had a chance to ask questions and all my questions have been answered.
- All issues related to privacy, and the confidentiality and use of the information I provide, have been explained.

By signing below, I ________________________________ *(name of participant)* agree to take part in this research study, as conducted by Christian Fourie.

____   ______________________

Signature of Participant   **Date**

DECLARATION BY THE PRINCIPAL INVESTIGATOR

As the **principal investigator,** I hereby declare that the information contained in this document has been thoroughly explained to the participant. I also declare that the participant has been encouraged (and has been given ample time) to ask any questions. In addition I would like to select the following option:

	The conversation with the participant was conducted in a language in which the participant is fluent.
	The conversation with the participant was conducted with the assistance of a translator (who has signed a non-disclosure agreement), and this "Consent Form" is available to the participant in a language in which the participant is fluent.

____   ______________________

Signature of Principal Investigator   **Date**

Questionnaire

Background

Asset Information (AI) is present and important in all life cycle stages of South African Navy (SAN) systems. In the acquisition life cycle stage the focus in terms of AI is on ensuring that the functional and logistic requirements are reflected in the engineering data. During the operational deployment and maintenance life cycle stage the data and information is used to maintain and operate the system. Data identification, structuring, capturing, processing, analysis, reporting, safekeeping, backup and archiving, the whole process of turning data into information and insight for decision support within the SAN must be managed.

During the operational deployment and maintenance phase the Operational Support Base Line (OSBL) and associated data generated, is required to support the system in actual conditions. Shortcomings in OSBL data affecting performance of the system, more specifically information requirements enabling asset related decision making, must be continuously monitored and corrected to sustain system readiness objectives i.e. operational availability (A_O). Asset Management (AM) in the DOD is centered around making the best life cycle decisions and must support the higher order system plans of the DOD's strategic objectives. This study is set specifically in the operational deployment and maintenance life cycle stage of a products system. The system is operational and must be managed to achieve the required A_O, using the available resources, one of which is AI.

The intention of the study is to uncover the role of specific AI elements in achieving A_O and form an AI decision making framework. The decision making framework can aid in decision making by providing perspective and insight as to what is the worth of various AI elements. Information costs money and comes with a measure of risk, but could also be very valuable. The decision making framework provides the means to quantify the preferences of a decision maker towards each of the conflicting criteria, as well as the ability to compare the normally incomparable criteria.

A top down approach is followed where the first round of survey based questionnaires established the important decisions that are made using AI by those involved in System Management in the SAN. Additionally, the experts were asked what AI elements are required for them to make their stated decisions.

The second questionnaire is based on Multi Attribute Utility Theory (MAUT), a decision support modelling technique. Initially the questionnaire elicits a utility function from the participant. After that the participant is asked to use his or her expert opinion to complete the data set for the three attributes associated with AI elements. As part of the data set, and at the crux of the second questionnaire, is providing an opinion on the value of each AI element identified in the first questionnaire towards achieving A_O. In order to better form an opinion the results of the first round of questionnaires are provided below in the tables.

Making use of the utility function and the completed attribute data set the AI elements are scored and ranked. The initial data set provides a baseline for the decision making framework to be validated against. Once validated, the preferences and data can be changed as required by the decision maker to yield results in support of decision making.

Survey

It is important that you answer the questions based on your experience in the SAN. There are no right or wrong answers, the study is seeking your expert opinion.
Answers can be written on the survey form, or typed out on additional pages if required. Please complete the survey within *2 weeks* of receiving the questionnaire.

Participant information

(Personal information is kept confidential, information pertaining to your experience is only used to prove validity of expert opinion)

Please supply the following information

Name: ____

Position: ____

Primary responsibilities: ____

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____

Years experience in your field: ____

Step 1: Utility function. Choosing the correct Asset Information elements to support decision making is essential to maximise Operational Availability of a system. There are however constraints involved such as cost and risk. With a limited budget the cost of some Asset Information elements might outweigh its value, similar with risk. Risk is a broad term that questions the validity of an Asset Information element based on the risk associated with for example time sensitivity of data, incorrect input data and the lack of input data. With the general objectives of maximising Operational Availability (AO) and minimizing Life Cycle Cost (LCC) as well as risk, a utility function is elicited. This utility assigns numerical values to the choice criteria (attributes) of Asset Information elements, which are normally incomparable. The utility is determined by the decision maker, based on preference and choices that involves tradeoffs. Using the utility, scores can be assigned to all possible choices, allowing ranking from most desireable to least desireable.	First compare the attribute in the row with the attribute in the column and choose which one of the two attributes is the most preferable. Enter the letter of the preferred attribute (x,y or z) in the first column. Secondly, thinking of a tradeoff, score both on a scale from 1 to 5, where 5 indicates the attribute is very important, 4 important, 3 indifference, 2 not important and 1 indicates that the attribute is absolutely unimportant relative to the other. When the two scores are compared a ratio of relative importance should be forthcoming. Example: If attribute A is preferred to attribute B and attribute A is important in comparison to attribute B which is absolutely not important in this tradeoff the entry will be A - 4 -1. (If both are of equal importance, even though one is preferred, score both attributes 3).

	Value to Ao - X			**Cost of Information - Y**			**Risk - Z**		
	Attribute	Score attribute preferred	Score attribute not preferred	Attribute	Score attribute chosen	Score attribute not chosen	Attribute	Score attribute chosen	Score attribute not chosen
Value to A_o - X									
Cost of Information - Y									
Risk - Z									

Step 2: Attribute data set. The mathematical values of the attributes are not known and must be assigned. In the absence of known values a rating scale from 1 to 10 is implemented to estimate these values.
Cost is a tangible concept, however, the cost of a particular Asset Information (AI) element is often difficult to isolate. Although not impossible, it falls outside the scope of this study. Therefore cost will be grouped with value and risk, which in this study are two intangible concepts that requires expert opinions in order to quantify them. Cost of Information and Risk are to be assigned values based on expert opinion and experience gained.
The value of AI elements to achieving operational availability (Value to AO) of SAN systems is of particular importance in this study as it has a direct impact on explaining the impact of different AI elements on operational availability. When assigning numbers to this attribute it is recommended that the data collection results of the previous survey be considered to help form an opinion. Experts were asked which are the most important decisions that they take affecting operational availability and what information elements are required to take these decisions. The results of those questionnaires were combined to form this questionnaire and are displayed in the table below. AI elements are the subject matter of this questionnaire. For consideration the number of occurrences that an AI element was deemed a requirement and the decisions it relates to are shown in the columns to the right of each AI element.
Please assign a value between 1 and 10 to each attribute of each AI element below. With 1 being low and 10 being high, the numbers in between have equal increments between the two end points. Intuitively one would maximise Value of AO, whilst minimizing cost and risk. This survey is set up to be answered as such; for example an AI element with a score of 9 - 1 - 1 for Value to AO, Cost of Information and Risk respectively is ranked higher than an AI element with a score of 2 - 8 - 8.

Asset Information element	Attributes			Metadata from previous survey	
	Value to Ao	Cost of Information	Risk	Number of occurrences	Decision related to
Accurate costing of spares and materials				4	Scheduled maintenance related decisions
					Re-supply of mission related products decisions
					Re-supply of spares related decisions
					Budgetary decisions
Accurate job-card feedback				3	Scheduled maintenance related decisions
					Re-supply of spares related decisions
					Re-supply of mission related products decisions
Allowances of original design parameters such as weight increase, load increase, usage increase as well as structural strength and integrity.				1	Changing the roles of vessels beyond designed roles as well as equipment life extension related decisions
Budget information				4	Re-supply of spares related decisions
					Execution of planned activities related decisions (daily management)
					New mission associated equipment procurement related decisions
					Obsolescence related decisions
Capacity of repair sections to conduct outstanding maintenance				1	Movement of maintenance periods due to operational requirements related decisions
Consumable products allowance lists				1	Re-supply of mission related products decisions
Accurate costing of services required				1	Budgetary decisions
Data showing the difference between predicted hours and material vs actual hours and material used per standard maintenance task				3	Re-supply of mission related products decisions
					Re-supply of spares related decisions
					Scheduled maintenance related decisions
Design change impact studies				1	Changing the roles of vessels beyond designed roles as well as equipment life extension related decisions
Divisions between mission critical spares and all planned spares				1	Budgetary decisions
Equipment required				3	Spares refurbishment related decisions
					Engineering change related decisions
					Scheduled maintenance related decisions
Equipment sensitivity towards number of uninstall and install procedures				1	Cannibalizing vessels to meet operational requirements related decisions

Asset Information element	Attributes			Metadata from previous survey	
	Value to Ao	Cost of Information	Risk	Number of occurrences	Decision related to
Expiration dates of stock in depot				1	Unscheduled repair related decisions
Failure rate data				3	Re-supply of mission related products decisions
					Re-supply of spares related decisions
					Scheduled maintenance related decisions
Handover procedures (record keeping)				1	Movement of key maintenance personnel due to operational requirements related decisions
Historical cost data				1	Budgetary decisions
Human resource personnel shortage prevention measure strategies				1	Movement of key maintenance personnel due to operational requirements related decisions
Human resource strategies and plans to replace maintenance personnel with suitably qualified stand in personnel				1	Movement of key maintenance personnel due to operational requirements related decisions
Industry support contract information				1	New mission associated equipment procurement related decisions
Information on alternatives available in the market				1	Obsolescence related decisions
Information on systems being operated in other military environments				1	Obsolescence related decisions
Information on the availability of skills and special tools at the relevant maintenance level				2	Unscheduled repair related decisions
					Scheduled maintenance related decisions
Information on what proportion of repairs are likely to take place at each level of maintenance				1	Unscheduled repair related decisions
Inventory levels				6	Re-supply of spares related decisions
					Re-supply of mission related products decisions
					Spares refurbishment related decisions
					Scheduled maintenance related decisions
					Unscheduled repair related decisions
					Budgetary decisions
Inventory re-order points				1	Budgetary decisions
LSA data				5	Re-supply of spares related decisions
					Obsolescence related decisions
					Re-supply of mission related products decisions
					Unscheduled repair related decisions
					Scheduled maintenance related decisions
Maintenance history				4	Scheduled maintenance related decisions
					Engineering change related decisions
					Spares refurbishment related decisions
					Unscheduled repair related decisions
Maintenance task information				1	Scheduled maintenance related decisions
Materiel and usage accounting				1	Cannibalizing vessels to meet operational requirements related decisions
Minimum stock levels				1	Budgetary decisions
Modification instructions				1	Engineering change related decisions
Number of candidates for refurbishment				1	Spares refurbishment related decisions
Number of each type of mission related products to be re-supplied				1	Re-supply of mission related products decisions
Number of each type of spares to be used in maintenance and other support activities				1	Re-supply of spares related decisions

Asset Information element	Attributes			Metadata from previous survey	
	Value to Ao	Cost of Information	Risk	Number of occurrences	Decision related to
Number of mission related products to be procured				1	New mission associated equipment procurement related decisions
Number of products likely to require modifications				1	Engineering change related decisions
Number of products requiring scheduled maintenance				1	Scheduled maintenance related decisions
Number of systems required to be online in a given period				1	Budgetary decisions
OEM Last time buy and technical support information				1	Obsolescence related decisions
Original product system acquisition plan				1	New mission associated equipment procurement related decisions
Period by which the maintenance downtime will be extended to catch up on maintenance once the product system is no longer operationally required				1	Movement of maintenance periods due to operational requirements related decisions
Predicted stock usage for planned activities				2	Re-supply of mission related products decisions
					Re-supply of spares related decisions
Previous refurbishment details				1	Spares refurbishment related decisions
Product lead time				1	Obsolescence related decisions
Projected equipment priorities				1	Level of ambition decisions
Projected missions				1	Level of ambition decisions
Qualified OSBL				1	Budgetary decisions
Readiness level required				1	Budgetary decisions
Required delivery schedule				2	Re-supply of mission related products decisions
					Re-supply of spares related decisions
Spares required				5	Engineering change related decisions
					Scheduled maintenance related decisions
					Budgetary decisions
					Unscheduled repair related decisions
					Spares refurbishment related decisions
Status of training facilities				1	Additional in house maintenance support and training related decisions
Status of training material and training aids				1	Additional in house maintenance support and training related decisions
Strategies to reduce readiness and usage levels to ease the utilization of equipment				1	Movement of maintenance periods due to operational requirements related decisions
Stock usage history				4	Re-supply of mission related products decisions
					Re-supply of spares related decisions
					Scheduled maintenance related decisions
					Budgetary decisions
Studies detailing the overall effect on operational availability if some sub systems are being used more than originally planned				1	Cannibalizing vessels to meet operational requirements related decisions
Studies on the long term effect of delaying maintenance on the product system				1	Movement of maintenance periods due to operational requirements related decisions
Supplier data				1	Budgetary decisions
Supplier production planning				1	New mission related equipment procurement related decisions
Supply lead times				1	Budgetary decisions
Target inventory levels				1	Budgetary decisions
Turnover amount of stock				1	Budgetary decisions
Unplanned breakdown information				1	Execution of planned activities related decisions (daily management)

Asset Information element	Attributes			Metadata from previous survey	
	Value to Ao	Cost of Information	Risk	Number of occurrences	Decision related to
Upcoming maintenance requirements				1	Re-supply of spares related decisions
Usage history				1	Spares refurbishment related decisions
What if scenario's and strategies related to reducing the number of available systems, maintenance of sub-systems, changing maintenance philosophy and changing training policies				1	Level of ambition decisions
Work to be performed				1	Spares refurbishment related decisions

Any other comments?

Appendix E

Second survey results

Preference values

Value to Ao - Utility Preference: Data set One	Two	Three	Mean across data sets	Standard deviation across data sets	Cost of Information - Utility Preference: Data set One	Two	Three	Mean across data sets	Standard deviation across data sets	Risk - Utility Preference: Data set One	Two	Three	Mean across data sets	Standard deviation across data sets
50%	37%	33%	40%	9%	17%	30%	33%	27%	9%	33%	33%	33%	33%	0%

Asset Information attribute values

		Utility Mean	Utility Std. Dev.	UT(1)	UT(2)	UT(3)	Value to Ao - Attributes: Data set One	Two	Three	Mean across data sets	Standard deviation across data sets	Cost of Information - Attributes: Data set One	Two	Three	Mean across data sets	Standard deviation across data sets	Risk - Attributes: Data set One	Two	Three	Mean across data sets	Standard deviation across data sets
Accurate costing of spares and materials	Item 1	5,723	0,526	5,680	5,220	6,270	4	9	7	6,667	2,517	1	8	6	5,000	3,606	5	8	4	5,667	2,082
Accurate job-card feedback	Item 2	5,837	1,017	7,010	5,220	5,280	6	9	9	8,000	1,732	1	8	9	6,000	4,359	4	8	6	6,000	2,000
Allowances of original design parameters such as weight increase, load increase, usage increase as well as structural strength and integrity.	Item 3	6,693	2,891	3,850	9,630	6,600	1	9	8	6,000	4,359	1	1	9	3,667	4,619	6	1	1	2,667	2,887
Budget information	Item 4	8,183	1,916	6,010	9,630	8,910	4	9	10	7,667	3,215	1	1	1	1,000	0,000	4	1	4	3,000	1,732
Capacity of repair sections to conduct outstanding maintenance	Item 5	7,087	2,212	6,020	9,630	5,610	6	9	6	7,000	1,732	1	1	5	2,333	2,309	7	1	6	4,667	3,215
Consumable products allowance lists	Item 6	7,140	2,175	6,180	9,630	5,610	5	9	5	6,333	2,309	1	1	5	2,333	2,309	5	1	5	3,667	2,309
Accurate costing of services required	Item 7	5,557	0,618	5,180	5,220	6,270	3	9	10	7,333	3,786	1	8	10	6,333	4,726	5	8	3	5,333	2,517
Data showing the difference between predicted hours and material vs actual hours and material used per	Item 8	5,280	0,961	4,350	5,220	6,270	2	9	8	6,333	3,786	1	8	9	6,000	4,359	6	8	2	5,333	3,055
Design change impact studies	Item 9	5,530	0,070	5,500	5,480	5,610	1	8	5	4,667	3,512	1	7	9	5,667	4,163	1	7	1	3,000	3,464
Divisions between mission critical spares and all planned spares	Item 10	4,903	2,370	6,840	2,260	5,610	5	1	9	5,000	4,000	1	8	9	6,000	4,359	3	8	5	5,333	2,517
Equipment required	Item 11	6,740	1,491	6,680	8,260	5,280	6	7	9	7,333	1,528	1	2	9	4,000	4,359	5	2	6	4,333	2,082
Equipment sensitivity towards number of uninstall and install procedures	Item 12	6,767	1,693	4,820	7,890	7,590	1	6	9	5,333	4,041	5	2	7	4,667	2,517	1	2	1	1,333	0,577
Expiration dates of stock in depot	Item 13	5,413	2,453	6,350	2,630	7,260	6	2	9	5,667	3,512	1	8	3	4,000	3,606	6	8	6	6,667	1,155
Failure rate data	Item 14	5,440	0,434	5,160	5,220	5,940	4	9	9	7,333	2,887	6	8	9	7,667	1,528	4	8	4	5,333	2,309
Handover procedures (record keeping)	Item 15	6,230	2,029	4,850	8,560	5,280	3	7	6	5,333	2,082	1	1	9	3,667	4,619	6	2	3	3,667	2,082
Historical cost data	Item 16	6,753	1,215	6,170	8,150	5,940	3	5	6	4,667	1,528	1	1	7	3,000	3,464	2	1	3	2,000	1,000
Human resource personnel shortage prevention measure strategies	Item 17	7,170	1,437	5,690	8,560	7,260	6	7	9	7,333	1,528	1	1	3	1,667	1,155	8	2	6	5,333	3,055
Human resource strategies and plans to replace maintenance personnel with suitably qualified stand in personnel	Item 18	7,230	1,189	6,860	8,560	6,270	9	7	9	8,333	1,155	1	1	3	1,667	1,155	9	2	9	6,667	4,041
Industry support contract information	Item 19	6,650	1,039	5,500	7,520	6,930	1	5	9	5,000	4,000	1	2	9	4,000	4,359	1	2	1	1,333	0,577
Information on alternatives available in the market	Item 20	5,963	1,765	4,490	5,480	7,920	2	8	7	5,667	3,215	6	7	3	5,333	2,082	3	7	2	4,000	2,646
Information on systems being operated in other military environments	Item 21	5,120	2,864	4,480	2,630	8,250	1	2	7	3,333	3,215	7	8	3	6,000	2,646	1	8	1	3,333	4,041
Information on the availability of skills and special tools at the relevant maintenance level	Item 22	5,270	0,586	5,020	4,850	5,940	4	8	9	7,000	2,646	1	8	9	6,000	4,359	7	8	4	6,333	2,082
Information on what proportion of repairs are likely to take place at each level of maintenance	Item 23	5,427	0,548	5,490	4,850	5,940	4	8	9	7,000	2,646	6	8	9	7,667	1,528	3	8	4	5,000	2,646
Inventory levels	Item 24	5,283	0,627	4,690	5,220	5,940	4	9	10	7,667	3,215	1	8	10	6,333	4,726	8	8	4	6,667	2,309
Inventory re-order points	Item 25	5,673	0,734	6,520	5,220	5,280	7	9	9	8,333	1,155	1	8	8	5,667	4,041	7	8	7	7,333	0,577
LSA data	Item 26	4,843	0,380	4,660	4,590	5,280	4	9	8	7,000	2,646	7	9	10	8,667	1,528	5	9	4	6,000	2,646
Maintenance history	Item 27	6,180	1,395	5,160	7,770	5,610	4	9	8	7,000	2,646	6	5	9	6,667	2,082	4	3	4	3,667	0,577
Maintenance task information	Item 28	5,653	0,629	6,160	5,850	4,950	6	9	8	7,667	1,528	6	7	9	7,333	1,528	4	7	6	5,667	1,528
Materiel and usage accounting	Item 29	5,433	0,528	4,840	5,850	5,610	3	9	7	6,333	3,055	3	7	9	6,333	3,055	5	7	3	5,000	2,000
Minimum stock levels	Item 30	5,210	1,187	3,840	5,850	5,940	3	9	8	6,667	3,215	5	7	9	7,000	2,000	7	7	3	5,667	2,309
Modification instructions	Item 31	6,147	1,439	4,650	7,520	6,270	2	5	6	4,333	2,082	7	2	7	5,333	2,887	2	2	2	2,000	0,000
Number of candidates for refurbishment	Item 32	6,687	1,901	4,830	8,630	6,600	2	8	5	5,000	3,000	4	2	5	3,667	1,528	3	2	2	2,333	0,577
Number of each type of mission related products to be re-supplied	Item 33	5,480	0,200	5,680	5,480	5,280	6	8	7	7,000	1,000	3	7	7	5,667	2,309	7	7	6	6,667	0,577
Number of each type of spares to be used in maintenance and other support activities	Item 34	5,703	0,886	6,680	5,480	4,950	7	8	9	8,000	1,000	2	7	9	6,000	3,606	6	7	7	6,667	0,577
Number of mission related products to be procured	Item 35	6,390	0,718	7,160	5,740	6,270	7	7	9	7,667	1,155	5	6	5	5,333	0,577	3	6	7	5,333	2,082
Number of products likely to require modifications	Item 36	5,917	1,057	4,820	6,000	6,930	2	6	7	5,000	2,646	6	5	6	5,667	0,577	2	5	2	3,000	1,732
Number of products requiring scheduled maintenance	Item 37	5,510	1,065	6,690	5,220	4,620	8	9	9	8,667	0,577	1	8	9	6,000	4,359	8	8	8	8,000	0,000
Number of systems required to be online in a given period	Item 38	5,453	0,750	5,830	4,590	5,940	4	9	9	7,333	2,887	4	9	9	7,333	2,887	3	9	4	5,333	3,215
OEM Last time buy and technical support information	Item 39	4,953	0,864	4,330	4,590	5,940	3	9	9	7,000	3,464	6	9	10	8,333	2,082	5	9	3	5,667	3,055
Original product system acquisition plan	Item 40	5,870	1,247	5,500	4,850	7,260	1	8	9	6,000	4,359	1	8	8	5,667	4,041	1	8	1	3,333	4,041
Period by which the maintenance downtime will be extended to catch up on maintenance once the product system is no longer operationally required	Item 41	6,460	1,068	5,500	7,610	6,270		8	10	9,000	1,414		1	3	2,000	1,414		6	10	8,000	2,828
Predicted stock usage for planned activities	Item 42	5,187	0,744	6,020	4,590	4,950	7	9	9	8,333	1,155	2	9	9	6,667	4,041	8	9	7	8,000	1,000
Previous refurbishment details	Item 43	6,027	1,345	4,490	6,990	6,600	2	6	7	5,000	2,646	6	5	7	6,000	1,000	3	2	2	2,333	0,577
Product lead time	Item 44	6,360	1,415	5,160	6,000	7,920	2	6	10	6,000	4,000	4	5	6	5,000	1,000	2	5	2	3,000	1,732
Projected equipment priorities	Item 45	6,750	1,436	6,820	8,150	5,280	7	5	9	7,000	2,000	7	1	8	5,333	3,786	3	1	7	3,667	3,055
Projected missions	Item 46	6,970	1,045	6,160	8,150	6,600	6	5	10	7,000	2,646	6	1	6	4,333	2,887	4	1	6	3,667	2,517
Qualified OSBL	Item 47	5,477	0,290	5,340	5,810	5,280	7	8	8	7,667	0,577	6	7	7	6,667	0,577	8	6	7	7,000	1,000

							Value to Ao - Attributes					Cost of Information - Attributes					Risk - Attributes				
							Data set					Data set					Data set				
		Utility Mean	Utility Std. Dev.	UT(1)	UT(2)	UT(3)	One	Two	Three	Mean across data sets	Standard deviation across data sets	One	Two	Three	Mean across data sets	Standard deviation across data sets	One	Two	Three	Mean across data sets	Standard deviation across data sets
Readiness level required	Item 48	6,573	1,679	4,660	7,800	7,260	2	9	8	6,333	3,786	5	6	6	5,667	0,577	3	2	2	2,333	0,577
Required delivery schedule	Item 49	6,793	1,690	7,160	8,270	4,950	7	8	7	7,333	0,577	5	1	7	4,333	3,055	3	4	7	4,667	2,082
Spares required	Item 50	5,663	1,122	6,850	5,520	4,620	9	9	10	9,333	0,577	3	7	9	6,333	3,055	8	8	9	8,333	0,577
Status of training facilities	Item 51	6,400	1,968	4,340	8,260	6,600	4	7	10	7,000	3,000	5	2	8	5,000	3,000	7	2	4	4,333	2,517
Status of training material and training aids	Item 52	6,730	1,469	5,330	8,260	6,600	5	7	10	7,333	2,517	6	2	7	5,000	2,646	5	2	5	4,000	1,732
Strategies to reduce readiness and usage levels to ease the utilization of equipment	Item 53	6,447	3,132	2,830	8,260	8,250	1	7	9	5,667	4,163	7	2	5	4,667	2,517	6	2	1	3,000	2,646
Stock usage history	Item 54	5,550	0,624	5,160	5,220	6,270	3	9	9	7,000	3,464	5	8	9	7,333	2,082	3	8	3	4,667	2,887
Studies detailing the overall effect on operational availability if some sub systems are being used more than originally planned	Item 55	5,577	1,308	4,320	5,480	6,930	2	8	8	6,000	3,464	7	7	7	7,000	0,000	3	7	2	4,000	2,646
Studies on the long term effect of delaying maintenance on the product system	Item 56	5,573	1,642	3,980	5,480	7,260	1	8	8	5,667	4,041	8	7	7	7,333	0,577	2	7	1	3,333	3,215
Supplier data	Item 57	5,957	1,184	6,680	4,590	6,600	7	9	9	8,333	1,155	2	9	4	5,000	3,606	6	9	7	7,333	1,528
Supplier production planning	Item 58	6,380	1,631	4,650	7,890	6,600	2	6	9	5,667	3,512	7	2	9	6,000	3,606	2	2	2	2,000	0,000
Supply lead times	Item 59	6,927	2,013	7,830	8,330	4,620	8	8	9	8,333	0,577	4	3	9	5,333	3,215	3	2	8	4,333	3,215
Target inventory levels	Item 60	5,763	0,641	6,490	5,520	5,280	6	9	9	8,000	1,732	6	7	9	7,333	1,528	3	8	6	5,667	2,517
Turnover amount of stock	Item 61	6,910	1,553	6,490	8,630	5,610	5	8	9	7,333	2,082	5	2	9	5,333	3,512	2	2	5	3,000	1,732
Unplanned breakdown information	Item 62	6,417	2,520	3,650	7,020	8,580	2	9	9	6,667	4,041	9	2	3	4,667	3,786	4	8	2	4,667	3,055
Upcoming maintenance requirements	Item 63	6,753	1,711	6,350	8,630	5,280	8	8	9	8,333	0,577	3	2	7	4,000	2,646	8	2	8	6,000	3,464
Usage history	Item 64	5,327	1,223	4,160	5,220	6,600	2	9	9	6,667	4,041	6	8	9	7,667	1,528	4	8	2	4,667	3,055
What if scenario's and strategies related to reducing the number of available systems, maintenance of sub-systems, changing maintenance philosophy and changing training policies	Item 65	5,520	1,061	4,480	5,480	6,600	2	8	9	6,333	3,786	8	7	9	8,000	1,000	2	7	2	3,667	2,887
Work to be performed	Item 66	7,030	1,680	7,180	8,630	5,280	8	8	9	8,333	0,577	2	2	7	3,667	2,887	6	2	8	5,333	3,055
		Max SD	3,132							Max SD	4,359				Max SD	4,726				Max SD	4,041
		Min SD	0,070							Min SD	0,577				Min SD	0,000				Min SD	0,000
										SD > 2	43				SD > 2	45				SD > 2	40
										1 < = SD >= 2	16				1 < = SD >= 2	14				1 < = SD >= 2	13
										SD < 1	7				SD < 1	7				SD < 1	13

Appendix F

South African Navy asset information decision making framework

	Asset Information element	Attributes (Scale 1 to 10)			Calc scores - inverse Cost & Risk			Utility Score	Rank - descending order of preference
		Value to Ao	Cost of Information	Risk	Value to Ao	Cost of Information	Risk		
Item 4	Budget information	7,667	1,000	3,000	7,667	10,000	8,000	8,183	1
Item 18	Human resource strategies and plans to replace maintenance personnel with suitably qualified stand in personnel	8,333	1,667	6,667	8,333	9,333	4,333	7,230	2
Item 17	Human resource personnel shortage prevention measure strategies	7,333	1,667	5,333	7,333	9,333	5,667	7,170	3
Item 6	Consumable products allowance lists	6,333	2,333	3,667	6,333	8,667	7,333	7,140	4
Item 5	Capacity of repair sections to conduct outstanding maintenance	7,000	2,333	4,667	7,000	8,667	6,333	7,087	5
Item 66	Work to be performed during maintenance or alterations to equipment	8,333	3,667	5,333	8,333	7,333	5,667	7,030	6
Item 46	Projected missions	7,000	4,333	3,667	7,000	6,667	7,333	6,970	7
Item 59	Supply lead times	8,333	5,333	4,333	8,333	5,667	6,667	6,927	8
Item 61	Turnover amount of stock	7,333	5,333	3,000	7,333	5,667	8,000	6,910	9
Item 49	Required delivery schedule	7,333	4,333	4,667	7,333	6,667	6,333	6,793	10
Item 12	Equipment sensitivity towards number of uninstall and install procedures	5,333	4,667	1,333	5,333	6,333	9,667	6,767	11
Item 63	Upcoming maintenance requirements	8,333	4,000	6,000	8,333	7,000	5,000	6,753	12
Item 16	Historical cost data	4,667	3,000	2,000	4,667	8,000	9,000	6,753	13
Item 45	Projected equipment priorities	7,000	5,333	3,667	7,000	5,667	7,333	6,750	14
Item 11	Equipment required to perform maintenance and alteration work on equipment	7,333	4,000	4,333	7,333	7,000	6,667	6,740	15
Item 52	Status of training material and training aids	7,333	5,000	4,000	7,333	6,000	7,000	6,730	16
Item 3	Allowances of original design parameters such as weight increase, load increase, usage increase as well as structural strength and integrity.	6,000	3,667	2,667	6,000	7,333	8,333	6,693	17
Item 32	Number of candidates for refurbishment	5,000	3,667	2,333	5,000	7,333	8,667	6,687	18
Item 19	Industry support contract information	5,000	4,000	1,333	5,000	7,000	9,667	6,650	19
Item 48	Readiness level required	6,333	5,667	2,333	6,333	5,333	8,667	6,573	20
Item 41	Period by which the maintenance downtime will be extended to catch up on maintenance once the product system is no longer operationally required	9,000	2,000	8,000	9,000	9,000	3,000	6,460	21
Item 54	Stock usage history	7,000	7,333	4,667	7,000	3,667	6,333	6,447	22
Item 62	Unplanned breakdown information	6,667	4,667	4,667	6,667	6,333	6,333	6,417	23
Item 51	Status of training facilities	7,000	5,000	4,333	7,000	6,000	6,667	6,400	24
Item 35	Number of mission related products to be procured	7,667	5,333	5,333	7,667	5,667	5,667	6,390	25
Item 58	Supplier production planning	5,667	6,000	2,000	5,667	5,000	9,000	6,380	26
Item 44	Product lead time	6,000	5,000	3,000	6,000	6,000	8,000	6,360	27
Item 15	Handover procedures (record keeping)	5,333	3,667	3,667	5,333	7,333	7,333	6,230	28
Item 27	Maintenance history	7,000	6,667	3,667	7,000	4,333	7,333	6,180	29
Item 31	Modification instructions	4,333	5,333	2,000	4,333	5,667	9,000	6,147	30
Item 43	Previous refurbishment details	5,000	6,000	2,333	5,000	5,000	8,667	6,027	31
Item 20	Information on alternatives available in the market	5,667	5,333	4,000	5,667	5,667	7,000	5,963	32
Item 57	Supplier data	8,333	5,000	7,333	8,333	6,000	3,667	5,957	33
Item 36	Number of products likely to require modifications	5,000	5,667	3,000	5,000	5,333	8,000	5,917	34
Item 40	Original product system acquisition plan	6,000	5,667	3,333	6,000	5,333	7,667	5,870	35
Item 2	Accurate job-card feedback	8,000	6,000	6,000	8,000	5,000	5,000	5,837	36
Item 60	Target inventory levels	8,000	7,333	5,667	8,000	3,667	5,333	5,763	37
Item 1	Accurate costing of spares and materials	6,667	5,000	5,667	6,667	6,000	5,333	5,723	38

	Asset Information element	Attributes (Scale 1 to 10)			Calc scores - inverse Cost & Risk			Utility Score	Rank - descending order of preference
		Value to Ao	Cost of Information	Risk	Value to Ao	Cost of Information	Risk		
Item 34	Number of each type of spares to be used in maintenance and other support activities	8,000	6,000	6,667	8,000	5,000	4,333	5,703	39
Item 25	Inventory re-order points	8,333	5,667	7,333	8,333	5,333	3,667	5,673	40
Item 50	Spares required for preventive and corrective maintenance as well as alterations on equipment	9,333	6,333	8,333	9,333	4,667	2,667	5,663	41
Item 28	Maintenance task information	7,667	7,333	5,667	7,667	3,667	5,333	5,653	42
Item 55	Studies detailing the overall effect on operational availability if some sub systems are being used more than originally planned	6,000	7,000	4,000	6,000	4,000	7,000	5,577	43
Item 56	Studies on the long term effect of delaying maintenance on the product system	5,667	7,333	3,333	5,667	3,667	7,667	5,573	44
Item 7	Accurate costing of services required	7,333	6,333	5,333	7,333	4,667	5,667	5,557	45
Item 53	Strategies to reduce readiness and usage levels to ease the utilization of equipment	5,667	4,667	3,000	5,667	6,333	8,000	5,550	46
Item 9	Design change impact studies	4,667	5,667	3,000	4,667	5,333	8,000	5,530	47
Item 65	What if scenario's and strategies related to reducing the number of available systems, maintenance of sub-systems, changing maintenance philosophy and changing training policies	6,333	8,000	3,667	6,333	3,000	7,333	5,520	48
Item 37	Number of products requiring scheduled maintenance	8,667	6,000	8,000	8,667	5,000	3,000	5,510	49
Item 33	Number of each type of mission related products to be re-supplied	7,000	5,667	6,667	7,000	5,333	4,333	5,480	50
Item 47	Qualified OSBL	7,667	6,667	7,000	7,667	4,333	4,000	5,477	51
Item 38	Number of systems required to be online in a given period	7,333	7,333	5,333	7,333	3,667	5,667	5,453	52
Item 14	Failure rate data	7,333	7,667	5,333	7,333	3,333	5,667	5,440	53
Item 29	Materiel and usage accounting	6,333	6,333	5,000	6,333	4,667	6,000	5,433	54
Item 23	Information on what proportion of repairs are likely to take place at each level of maintenance	7,000	7,667	5,000	7,000	3,333	6,000	5,427	55
Item 13	Expiration dates of stock in depot	5,667	4,000	6,667	5,667	7,000	4,333	5,413	56
Item 64	Usage history	6,667	7,667	4,667	6,667	3,333	6,333	5,327	57
Item 24	Inventory levels	7,667	6,333	6,667	7,667	4,667	4,333	5,283	58
Item 8	Data showing the difference between predicted hours and material vs actual hours and material used per standard maintenance task	6,333	6,000	5,333	6,333	5,000	5,667	5,280	59
Item 22	Information on the availability of skills and special tools at the relevant maintenance level	7,000	6,000	6,333	7,000	5,000	4,667	5,270	60
Item 30	Minimum stock levels	6,667	7,000	5,667	6,667	4,000	5,333	5,210	61
Item 42	Predicted stock usage for planned activities	8,333	6,667	8,000	8,333	4,333	3,000	5,187	62
Item 21	Information on systems being operated in other military environments	3,333	6,000	3,333	3,333	5,000	7,667	5,120	63
Item 39	OEM Last time buy and technical support information	7,000	8,333	5,667	7,000	2,667	5,333	4,953	64
Item 10	Divisions between mission critical spares and all planned spares	5,000	6,000	5,333	5,000	5,000	5,667	4,903	65
Item 26	LSA data	7,000	8,667	6,000	7,000	2,333	5,000	4,843	66

Appendix G

Least significant difference post hoc table

LSD test; variable lsmean (Table 5) Probabilities for Post Hoc Tests Error: Between MS =

Cell No.	item	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}	{10}	{11}	{12}	{13}	{14}	{15}	{16}	{17}	{18}	{19}	{20}	{21}	{22}	{23}	{24}	{25}	{26}	{27}	{28}	{29}	{30}	{31}	{32}	{33}	{34}	{35}	{36}	{37}	{38}	{39}	{40}	{41}	{42}	{43}	{44}	{45}	{46}	{47}	{48}	{49}	{50}	{51}	{52}	{53}	{54}	{55}	{56}	{57}	{58}	{59}	{60}	{61}	{62}	{63}	{64}	{65}	{66}
		8.1833	7.23	7.17	7.14	7.0867	7.03	6.97	6.9267	6.91	6.7933	6.7667	6.7533	6.7533	6.75	6.74	6.73	6.6933	6.6867	6.65	6.5733	6.46	6.4467	6.4167	6.4	6.39	6.38	6.36	6.23	6.18	6.1467	6.0267	5.9633	5.9567	5.9167	5.87	5.8367	5.7633	5.7233	5.7033	5.6733	5.6633	5.6533	5.5767	5.5733	5.5567	5.55	5.53	5.52	5.51	5.48	5.4767	5.4533	5.44	5.4333	5.4267	5.4133	5.3267	5.2833	5.28	5.27	5.21	5.1867	5.12	4.9533	4.9033	4.8433
1	Item 4		0.4	0.37	0.36	0.33	0.31	0.28	0.27	0.26	0.22	0.21	0.21	0.21	0.21	0.2	0.2	0.19	0.19	0.18	0.15	0.13	0.13	0.12	0.12	0.11	0.11	0.11	0.08	0.08	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0
2	Item 18	0.4		0.96	0.94	0.9	0.86	0.82	0.79	0.78	0.7	0.68	0.67	0.67	0.67	0.67	0.66	0.64	0.63	0.61	0.56	0.5	0.49	0.47	0.46	0.46	0.45	0.44	0.38	0.35	0.34	0.29	0.26	0.26	0.25	0.23	0.22	0.2	0.18	0.18	0.17	0.17	0.16	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.09	0.09	0.08	0.08	0.07	0.07	0.06	0.04	0.04	0.04
3	Item 17	0.37	0.96		0.98	0.94	0.9	0.86	0.83	0.82	0.74	0.72	0.71	0.71	0.71	0.7	0.7	0.67	0.67	0.65	0.6	0.53	0.52	0.51	0.5	0.49	0.49	0.47	0.41	0.38	0.37	0.31	0.29	0.28	0.27	0.25	0.24	0.21	0.2	0.2	0.19	0.18	0.18	0.16	0.16	0.15	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.12	0.12	0.1	0.1	0.1	0.09	0.08	0.08	0.07	0.05	0.05	0.04
4	Item 6	0.36	0.94	0.98		0.96	0.92	0.88	0.85	0.84	0.76	0.74	0.73	0.73	0.73	0.72	0.72	0.69	0.69	0.67	0.62	0.55	0.54	0.52	0.51	0.51	0.5	0.49	0.42	0.4	0.38	0.33	0.3	0.3	0.28	0.26	0.25	0.22	0.21	0.2	0.2	0.19	0.19	0.17	0.17	0.16	0.16	0.15	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.11	0.1	0.1	0.1	0.09	0.08	0.07	0.05	0.05	0.04
5	Item 5	0.33	0.9	0.94	0.96		0.96	0.92	0.89	0.88	0.8	0.78	0.77	0.77	0.77	0.76	0.75	0.73	0.72	0.7	0.65	0.58	0.57	0.55	0.54	0.54	0.53	0.52	0.45	0.42	0.41	0.35	0.32	0.32	0.3	0.28	0.27	0.24	0.23	0.22	0.21	0.21	0.21	0.18	0.18	0.18	0.17	0.17	0.17	0.16	0.16	0.15	0.15	0.15	0.14	0.14	0.14	0.12	0.11	0.11	0.11	0.1	0.09	0.08	0.06	0.05	0.05
6	Item 66	0.31	0.86	0.9	0.92	0.96		0.96	0.93	0.92	0.83	0.82	0.81	0.81	0.8	0.8	0.79	0.77	0.76	0.74	0.69	0.61	0.61	0.59	0.58	0.57	0.57	0.55	0.48	0.45	0.44	0.38	0.35	0.34	0.33	0.31	0.29	0.26	0.25	0.24	0.23	0.23	0.22	0.2	0.2	0.19	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.16	0.16	0.15	0.13	0.12	0.12	0.12	0.11	0.1	0.09	0.07	0.06	0.05
7	Item 46	0.28	0.82	0.86	0.88	0.92	0.96		0.97	0.96	0.88	0.86	0.85	0.85	0.85	0.84	0.83	0.81	0.8	0.78	0.73	0.65	0.64	0.62	0.61	0.61	0.6	0.59	0.51	0.49	0.47	0.4	0.37	0.37	0.35	0.33	0.32	0.29	0.27	0.26	0.25	0.25	0.24	0.22	0.22	0.21	0.21	0.2	0.2	0.2	0.19	0.19	0.18	0.18	0.17	0.17	0.17	0.15	0.14	0.14	0.13	0.12	0.12	0.1	0.07	0.07	0.06
8	Item 59	0.27	0.79	0.83	0.85	0.89	0.93	0.97		0.99	0.91	0.89	0.88	0.88	0.88	0.87	0.86	0.84	0.83	0.81	0.75	0.68	0.67	0.65	0.64	0.64	0.63	0.62	0.54	0.51	0.49	0.43	0.39	0.39	0.38	0.35	0.34	0.3	0.29	0.28	0.27	0.26	0.26	0.23	0.23	0.23	0.22	0.22	0.21	0.21	0.2	0.2	0.19	0.19	0.19	0.19	0.18	0.16	0.15	0.15	0.14	0.13	0.12	0.11	0.08	0.07	0.07
9	Item 61	0.26	0.78	0.82	0.84	0.88	0.92	0.96	0.99		0.92	0.9	0.89	0.89	0.89	0.88	0.87	0.85	0.84	0.82	0.77	0.69	0.68	0.66	0.65	0.65	0.64	0.63	0.55	0.52	0.5	0.44	0.39	0.4	0.38	0.36	0.34	0.31	0.29	0.29	0.27	0.27	0.27	0.24	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21	0.2	0.19	0.19	0.19	0.19	0.16	0.15	0.15	0.15	0.13	0.13	0.11	0.08	0.08	0.07
10	Item 49	0.22	0.7	0.74	0.76	0.8	0.83	0.88	0.91	0.92		0.98	0.97	0.97	0.97	0.96	0.96	0.93	0.92	0.9	0.85	0.77	0.76	0.74	0.73	0.72	0.72	0.7	0.62	0.59	0.57	0.5	0.46	0.46	0.44	0.41	0.4	0.36	0.34	0.34	0.32	0.32	0.31	0.28	0.28	0.27	0.27	0.26	0.26	0.26	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.2	0.18	0.18	0.18	0.16	0.16	0.14	0.1	0.1	0.08
11	Item 12	0.21	0.68	0.72	0.74	0.78	0.82	0.86	0.89	0.9	0.98		0.99	0.99	0.99	0.98	0.97	0.95	0.94	0.92	0.86	0.79	0.78	0.76	0.75	0.74	0.73	0.72	0.64	0.6	0.58	0.51	0.48	0.47	0.45	0.43	0.41	0.38	0.36	0.35	0.33	0.33	0.33	0.29	0.29	0.29	0.28	0.27	0.27	0.27	0.26	0.25	0.25	0.24	0.24	0.24	0.23	0.2	0.19	0.19	0.19	0.17	0.16	0.15	0.11	0.1	0.09
12	Item 63	0.21	0.67	0.71	0.73	0.77	0.81	0.85	0.88	0.89	0.97	0.99		1	1	0.99	0.98	0.96	0.95	0.93	0.87	0.8	0.79	0.77	0.75	0.75	0.74	0.73	0.64	0.61	0.59	0.52	0.49	0.48	0.46	0.44	0.42	0.38	0.36	0.35	0.34	0.34	0.33	0.3	0.3	0.29	0.29	0.28	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.24	0.21	0.19	0.19	0.19	0.17	0.17	0.15	0.11	0.1	0.09
13	Item 16	0.21	0.67	0.71	0.73	0.77	0.81	0.85	0.88	0.89	0.97	0.99	1		1	0.99	0.98	0.96	0.95	0.93	0.87	0.8	0.79	0.77	0.75	0.75	0.74	0.73	0.64	0.61	0.59	0.52	0.49	0.48	0.46	0.44	0.42	0.38	0.36	0.35	0.34	0.34	0.33	0.3	0.3	0.29	0.29	0.28	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.24	0.21	0.19	0.19	0.19	0.17	0.17	0.15	0.11	0.1	0.09
14	Item 45	0.21	0.67	0.71	0.73	0.77	0.8	0.85	0.88	0.89	0.97	0.99	1	1		0.99	0.99	0.96	0.96	0.93	0.88	0.8	0.79	0.77	0.76	0.75	0.74	0.73	0.65	0.61	0.59	0.52	0.49	0.48	0.46	0.44	0.42	0.38	0.36	0.36	0.34	0.34	0.33	0.3	0.3	0.29	0.29	0.28	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.24	0.21	0.2	0.19	0.19	0.17	0.17	0.15	0.11	0.1	0.09
15	Item 11	0.2	0.67	0.7	0.72	0.76	0.8	0.84	0.87	0.88	0.96	0.98	0.99	0.99	0.99		0.99	0.97	0.96	0.94	0.88	0.8	0.8	0.78	0.76	0.76	0.75	0.74	0.65	0.62	0.6	0.53	0.49	0.49	0.47	0.45	0.43	0.39	0.37	0.36	0.35	0.34	0.34	0.3	0.3	0.3	0.29	0.29	0.28	0.28	0.27	0.26	0.26	0.25	0.25	0.25	0.24	0.21	0.2	0.2	0.19	0.18	0.17	0.15	0.11	0.1	0.09
16	Item 52	0.2	0.66	0.7	0.72	0.75	0.79	0.83	0.86	0.87	0.96	0.97	0.98	0.98	0.99	0.99		0.97	0.97	0.94	0.89	0.81	0.8	0.78	0.77	0.76	0.76	0.74	0.66	0.63	0.61	0.53	0.5	0.49	0.47	0.45	0.43	0.39	0.37	0.36	0.35	0.35	0.34	0.31	0.31	0.3	0.3	0.29	0.29	0.28	0.27	0.27	0.26	0.25	0.25	0.25	0.24	0.22	0.2	0.2	0.2	0.18	0.17	0.15	0.12	0.11	0.1
17	Item 3	0.19	0.64	0.67	0.69	0.73	0.77	0.81	0.84	0.85	0.93	0.95	0.96	0.96	0.96	0.97	0.97		1	0.97	0.92	0.84	0.83	0.81	0.8	0.79	0.78	0.77	0.68	0.65	0.63	0.56	0.52	0.52	0.49	0.47	0.45	0.41	0.39	0.38	0.37	0.36	0.36	0.32	0.32	0.32	0.31	0.3	0.3	0.3	0.28	0.28	0.27	0.27	0.27	0.26	0.26	0.23	0.21	0.21	0.21	0.19	0.18	0.16	0.12	0.11	0.1
18	Item 32	0.19	0.63	0.67	0.69	0.72	0.76	0.8	0.83	0.84	0.92	0.94	0.95	0.95	0.96	0.96	0.97	1		0.97	0.92	0.84	0.83	0.81	0.8	0.79	0.79	0.77	0.69	0.65	0.63	0.56	0.52	0.52	0.5	0.47	0.45	0.41	0.39	0.39	0.37	0.37	0.36	0.33	0.33	0.32	0.32	0.31	0.3	0.3	0.29	0.29	0.28	0.27	0.27	0.27	0.26	0.23	0.22	0.21	0.21	0.19	0.19	0.17	0.13	0.12	0.1
19	Item 19	0.18	0.61	0.65	0.67	0.7	0.74	0.78	0.81	0.82	0.9	0.92	0.93	0.93	0.93	0.94	0.94	0.97	0.97		0.95	0.87	0.86	0.84	0.83	0.82	0.81	0.8	0.71	0.68	0.66	0.58	0.54	0.54	0.52	0.49	0.47	0.43	0.41	0.4	0.39	0.38	0.38	0.34	0.34	0.33	0.33	0.32	0.32	0.31	0.3	0.3	0.29	0.29	0.28	0.28	0.27	0.24	0.23	0.23	0.22	0.2	0.2	0.18	0.13	0.12	0.11
20	Item 48	0.15	0.56	0.6	0.62	0.65	0.69	0.73	0.75	0.77	0.85	0.86	0.87	0.87	0.88	0.88	0.89	0.92	0.92	0.95		0.92	0.91	0.89	0.88	0.87	0.86	0.85	0.76	0.73	0.71	0.63	0.59	0.59	0.56	0.53	0.52	0.47	0.45	0.44	0.43	0.42	0.42	0.38	0.38	0.37	0.37	0.36	0.35	0.35	0.33	0.33	0.32	0.32	0.31	0.31	0.31	0.27	0.25	0.25	0.25	0.23	0.22	0.2	0.15	0.14	0.13
21	Item 41	0.13	0.5	0.53	0.55	0.58	0.61	0.65	0.68	0.69	0.77	0.79	0.8	0.8	0.8	0.8	0.81	0.84	0.84	0.87	0.92		0.99	0.97	0.96	0.95	0.94	0.93	0.84	0.8	0.78	0.7	0.66	0.66	0.63	0.6	0.58	0.54	0.52	0.5	0.49	0.48	0.48	0.44	0.43	0.42	0.42	0.41	0.41	0.4	0.39	0.39	0.37	0.37	0.36	0.36	0.36	0.32	0.3	0.3	0.29	0.27	0.26	0.24	0.18	0.17	0.15
22	Item 53	0.13	0.49	0.52	0.54	0.57	0.61	0.64	0.67	0.68	0.76	0.78	0.79	0.79	0.79	0.8	0.8	0.83	0.83	0.86	0.91	0.99		0.98	0.97	0.96	0.95	0.94	0.85	0.81	0.79	0.71	0.67	0.67	0.64	0.61	0.59	0.55	0.52	0.51	0.49	0.49	0.48	0.44	0.44	0.43	0.43	0.42	0.41	0.41	0.39	0.39	0.38	0.37	0.37	0.37	0.36	0.32	0.3	0.3	0.3	0.27	0.27	0.24	0.19	0.17	0.16
23	Item 62	0.12	0.47	0.51	0.52	0.55	0.59	0.62	0.65	0.66	0.74	0.76	0.77	0.77	0.77	0.78	0.78	0.81	0.81	0.84	0.89	0.97	0.98		0.99	0.98	0.97	0.96	0.87	0.83	0.81	0.73	0.69	0.68	0.66	0.63	0.61	0.56	0.54	0.53	0.51	0.51	0.5	0.46	0.46	0.45	0.44	0.43	0.43	0.42	0.41	0.41	0.39	0.39	0.39	0.38	0.38	0.34	0.32	0.32	0.31	0.29	0.28	0.25	0.2	0.18	0.16
24	Item 51	0.12	0.46	0.5	0.51	0.54	0.58	0.61	0.64	0.65	0.73	0.75	0.75	0.75	0.76	0.76	0.77	0.8	0.8	0.83	0.88	0.96	0.97	0.99		0.99	0.99	0.97	0.88	0.85	0.82	0.74	0.7	0.7	0.67	0.64	0.62	0.57	0.55	0.54	0.52	0.52	0.51	0.47	0.47	0.46	0.45	0.44	0.44	0.43	0.42	0.41	0.4	0.4	0.39	0.39	0.38	0.34	0.32	0.32	0.32	0.29	0.28	0.26	0.2	0.19	0.17
25	Item 35	0.11	0.46	0.49	0.51	0.54	0.57	0.61	0.64	0.65	0.72	0.74	0.75	0.75	0.75	0.76	0.76	0.79	0.79	0.82	0.87	0.95	0.96	0.98	0.99		0.99	0.98	0.89	0.85	0.83	0.75	0.71	0.7	0.68	0.65	0.63	0.58	0.56	0.54	0.53	0.52	0.52	0.47	0.47	0.46	0.46	0.45	0.44	0.44	0.42	0.42	0.41	0.4	0.4	0.39	0.39	0.35	0.33	0.33	0.32	0.3	0.29	0.26	0.2	0.19	0.17
26	Item 58	0.11	0.45	0.49	0.5	0.53	0.57	0.6	0.63	0.64	0.72	0.73	0.74	0.74	0.74	0.75	0.76	0.78	0.79	0.81	0.86	0.94	0.95	0.97	0.99	0.99		0.99	0.89	0.86	0.84	0.75	0.71	0.71	0.68	0.65	0.63	0.59	0.56	0.55	0.53	0.53	0.52	0.48	0.48	0.47	0.46	0.45	0.45	0.44	0.43	0.42	0.41	0.41	0.4	0.4	0.39	0.35	0.33	0.33	0.33	0.3	0.29	0.27	0.21	0.19	0.17
27	Item 44	0.11	0.44	0.47	0.49	0.52	0.55	0.59	0.62	0.63	0.7	0.72	0.73	0.73	0.73	0.74	0.74	0.77	0.77	0.8	0.85	0.93	0.94	0.96	0.97	0.98	0.99		0.91	0.87	0.85	0.77	0.73	0.72	0.7	0.67	0.64	0.6	0.57	0.56	0.54	0.54	0.53	0.49	0.49	0.48	0.47	0.46	0.46	0.45	0.44	0.44	0.42	0.42	0.41	0.41	0.4	0.36	0.34	0.34	0.34	0.31	0.3	0.27	0.21	0.2	0.18
28	Item 15	0.08	0.38	0.41	0.42	0.45	0.48	0.51	0.54	0.55	0.62	0.64	0.64	0.64	0.65	0.65	0.66	0.68	0.69	0.71	0.76	0.84	0.85	0.87	0.88	0.89	0.89	0.91		0.96	0.94	0.86	0.81	0.81	0.78	0.75	0.73	0.68	0.65	0.64	0.62	0.62	0.61	0.56	0.56	0.55	0.55	0.54	0.53	0.52	0.51	0.51	0.49	0.49	0.48	0.48	0.47	0.42	0.4	0.4	0.4	0.37	0.36	0.33	0.26	0.24	0.22
29	Item 27	0.08	0.35	0.38	0.4	0.42	0.45	0.49	0.51	0.52	0.59	0.6	0.61	0.61	0.61	0.62	0.63	0.65	0.65	0.68	0.73	0.8	0.81	0.83	0.85	0.85	0.86	0.87	0.96		0.98	0.89	0.85	0.84	0.82	0.78	0.76	0.71	0.69	0.67	0.65	0.65	0.64	0.59	0.59	0.58	0.58	0.57	0.56	0.55	0.54	0.53	0.52	0.51	0.51	0.51	0.5	0.45	0.43	0.43	0.42	0.39	0.38	0.35	0.28	0.26	0.24
30	Item 31	0.07	0.34	0.37	0.38	0.41	0.44	0.47	0.49	0.5	0.57	0.58	0.59	0.59	0.59	0.6	0.61	0.63	0.63	0.66	0.71	0.78	0.79	0.81	0.82	0.83	0.84	0.85	0.94	0.98		0.92	0.87	0.87	0.84	0.81	0.78	0.73	0.71	0.7	0.68	0.67	0.66	0.61	0.61	0.6	0.6	0.59	0.58	0.57	0.56	0.55	0.54	0.53	0.53	0.52	0.52	0.47	0.45	0.44	0.44	0.41	0.4	0.36	0.29	0.27	0.25
31	Item 43	0.06	0.29	0.31	0.33	0.35	0.38	0.4	0.43	0.44	0.5	0.51	0.52	0.52	0.52	0.53	0.53	0.56	0.56	0.58	0.63	0.7	0.71	0.73	0.74	0.75	0.75	0.77	0.86	0.89	0.92		0.96	0.95	0.92	0.89	0.87	0.82	0.79	0.78	0.75	0.75	0.74	0.69	0.69	0.68	0.67	0.66	0.65	0.65	0.63	0.63	0.61	0.6	0.6	0.6	0.59	0.54	0.51	0.51	0.5	0.47	0.46	0.42	0.34	0.32	0.3
32	Item 20	0.05	0.26	0.29	0.3	0.32	0.35	0.37	0.39	0.39	0.46	0.48	0.49	0.49	0.49	0.49	0.5	0.52	0.52	0.54	0.59	0.66	0.67	0.69	0.7	0.71	0.71	0.73	0.81	0.85	0.87	0.96		1	0.97	0.93	0.91	0.86	0.83	0.82	0.8	0.79	0.78	0.73	0.73	0.72	0.72	0.7	0.7	0.69	0.67	0.67	0.65	0.64	0.64	0.64	0.63	0.57	0.55	0.55	0.54	0.51	0.49	0.46	0.37	0.35	0.32
33	Item 57	0.05	0.26	0.28	0.3	0.32	0.34	0.37	0.39	0.4	0.46	0.47	0.48	0.48	0.48	0.49	0.49	0.52	0.52	0.54	0.59	0.66	0.67	0.68	0.7	0.7	0.71	0.72	0.81	0.84	0.87	0.95	1		0.97	0.94	0.92	0.86	0.84	0.82	0.8	0.8	0.79	0.74	0.73	0.72	0.72	0.71	0.7	0.69	0.67	0.67	0.66	0.65	0.64	0.64	0.63	0.58	0.55	0.55	0.54	0.51	0.5	0.46	0.38	0.35	0.33
34	Item 36	0.05	0.25	0.27	0.28	0.3	0.33	0.35	0.38	0.38	0.44	0.45	0.46	0.46	0.46	0.47	0.47	0.49	0.5	0.52	0.56	0.63	0.64	0.66	0.67	0.68	0.68	0.7	0.78	0.82	0.84	0.92	0.97	0.97		0.97	0.94	0.89	0.86	0.85	0.83	0.82	0.82	0.76	0.76	0.75	0.75	0.73	0.73	0.72	0.7	0.7	0.68	0.67	0.67	0.67	0.66	0.6	0.58	0.57	0.57	0.53	0.52	0.48	0.39	0.37	0.34
35	Item 40	0.04	0.23	0.25	0.26	0.28	0.31	0.33	0.35	0.36	0.41	0.43	0.44	0.44	0.44	0.45	0.45	0.47	0.47	0.49	0.53	0.6	0.61	0.63	0.64	0.65	0.65	0.67	0.75	0.78	0.81	0.89	0.93	0.94	0.97		0.98	0.92	0.9	0.88	0.86	0.86	0.85	0.8	0.79	0.78	0.78	0.76	0.76	0.75	0.73	0.73	0.71	0.7	0.7	0.7	0.69	0.63	0.6	0.6	0.6	0.56	0.55	0.51	0.42	0.39	0.36
36	Item 2	0.04	0.22	0.24	0.25	0.27	0.29	0.32	0.34	0.34	0.4	0.41	0.42	0.42	0.42	0.43	0.43	0.45	0.45	0.47	0.52	0.58	0.59	0.61	0.62	0.63	0.63	0.64	0.73	0.76	0.78	0.87	0.91	0.92	0.94	0.98		0.95	0.92	0.91	0.89	0.88	0.87	0.82	0.82	0.8	0.8	0.79	0.78	0.77	0.75	0.75	0.73	0.73	0.72	0.72	0.71	0.65	0.62	0.62	0.62	0.58	0.57	0.53	0.44	0.41	0.38
37	Item 60	0.03	0.2	0.21	0.22	0.24	0.26	0.29	0.3	0.31	0.36	0.38	0.38	0.38	0.38	0.39	0.39	0.41	0.41	0.43	0.47	0.54	0.55	0.56	0.57	0.58	0.59	0.6	0.68	0.71	0.73	0.82	0.86	0.86	0.89	0.92	0.95		0.97	0.96	0.94	0.93	0.92	0.87	0.87	0.86	0.85	0.84	0.83	0.82	0.8	0.8	0.78	0.78	0.77	0.77	0.76	0.7	0.67	0.67	0.66	0.62	0.61	0.57	0.47	0.45	0.42
38	Item 1	0.03	0.18	0.2	0.21	0.23	0.25	0.27	0.29	0.29	0.34	0.36	0.36	0.36	0.36	0.37	0.37	0.39	0.39	0.41	0.45	0.52	0.52	0.54	0.55	0.56	0.56	0.57	0.65	0.69	0.71	0.79	0.83	0.84	0.86	0.9	0.92	0.97		0.99	0.96	0.96	0.95	0.9	0.89	0.88	0.88	0.86	0.86	0.85	0.83	0.83	0.81	0.8	0.8	0.79	0.78	0.73	0.7	0.7	0.69	0.65	0.64	0.59	0.5	0.47	0.44
39	Item 34	0.03	0.18	0.2	0.2	0.22	0.24	0.26	0.28	0.29	0.34	0.35	0.35	0.35	0.36	0.36	0.36	0.38	0.39	0.4	0.44	0.5	0.51	0.53	0.54	0.54	0.55	0.56	0.64	0.67	0.7	0.78	0.82	0.82	0.85	0.88	0.91	0.96	0.99		0.98	0.97	0.96	0.91	0.91	0.9	0.89	0.88	0.87	0.86	0.84	0.84	0.83	0.82	0.81	0.81	0.8	0.74	0.71	0.71	0.7	0.66	0.65	0.61	0.51	0.48	0.45
40	Item 25	0.03	0.17	0.19	0.2	0.21	0.23	0.25	0.27	0.27	0.32	0.33	0.34	0.34	0.34	0.35	0.35	0.37	0.37	0.39	0.43	0.49	0.49	0.51	0.52	0.53	0.53	0.54	0.62	0.65	0.68	0.75	0.8	0.8	0.83	0.86	0.89	0.94	0.96	0.98		0.99	0.99	0.93	0.93	0.92	0.91	0.9	0.89	0.89	0.86	0.86	0.85	0.84	0.83	0.83	0.82	0.76	0.73	0.73	0.72	0.68	0.67	0.62	0.52	0.5	0.46
41	Item 50	0.03	0.17	0.18	0.19	0.21	0.23	0.25	0.26	0.27	0.32	0.33	0.34	0.34	0.34	0.34	0.35	0.36	0.37	0.38	0.42	0.48	0.49	0.51	0.52	0.52	0.53	0.54	0.62	0.65	0.67	0.75	0.79	0.8	0.82	0.86	0.88	0.93	0.96	0.97	0.99		0.99	0.94	0.94	0.92	0.92	0.91	0.9	0.89	0.87	0.87	0.85	0.84	0.84	0.83	0.83	0.77	0.74	0.73	0.73	0.69	0.67	0.63	0.53	0.5	0.47
42	Item 28	0.03	0.16	0.18	0.19	0.21	0.22	0.24	0.26	0.27	0.31	0.33	0.33	0.33	0.33	0.34	0.34	0.36	0.36	0.38	0.42	0.48	0.48	0.5	0.51	0.52	0.52	0.53	0.61	0.64	0.66	0.74	0.78	0.79	0.82	0.85	0.87	0.92	0.95	0.96	0.99	0.99		0.95	0.94	0.93	0.93	0.91	0.91	0.9	0.88	0.88	0.86	0.85	0.85	0.84	0.83	0.77	0.74	0.74	0.73	0.7	0.68	0.64	0.54	0.51	0.47
43	Item 55	0.02	0.14	0.16	0.17	0.18	0.2	0.22	0.23	0.24	0.28	0.29	0.3	0.3	0.3	0.3	0.31	0.32	0.33	0.34	0.38	0.44	0.44	0.46	0.47	0.47	0.48	0.49	0.56	0.59	0.61	0.69	0.73	0.74	0.76	0.8	0.82	0.87	0.9	0.91	0.93	0.94	0.95		1	0.99	0.98	0.97	0.96	0.95	0.93	0.93	0.91	0.9	0.9	0.89	0.89	0.83	0.8	0.79	0.79	0.75	0.73	0.69	0.58	0.55	0.52
44	Item 56	0.02	0.14	0.16	0.17	0.18	0.2	0.22	0.23	0.24	0.28	0.29	0.3	0.3	0.3	0.3	0.31	0.32	0.33	0.34	0.38	0.43	0.44	0.46	0.47	0.47	0.48	0.49	0.56	0.59	0.61	0.69	0.73	0.73	0.76	0.79	0.82	0.87	0.89	0.91	0.93	0.94	0.94	1		0.99	0.98	0.97	0.96	0.96	0.93	0.93	0.92	0.91	0.9	0.9	0.89	0.83	0.8	0.8	0.79	0.75	0.73	0.69	0.58	0.55	0.52
45	Item 7	0.02	0.14	0.15	0.16	0.18	0.19	0.21	0.23	0.23	0.27	0.29	0.29	0.29	0.29	0.3	0.3	0.32	0.32	0.33	0.37	0.42	0.43	0.45	0.46	0.46	0.47	0.48	0.55	0.58	0.6	0.68	0.72	0.72	0.75	0.78	0.8	0.86	0.88	0.9	0.92	0.92	0.93	0.99	0.99		1	0.98	0.97	0.97	0.95	0.94	0.93	0.92	0.91	0.91	0.9	0.84	0.81	0.81	0.8	0.76	0.74	0.7	0.59	0.56	0.53
46	Item 54	0.02	0.14	0.15	0.16	0.17	0.19	0.21	0.22	0.23	0.27	0.28	0.29	0.29	0.29	0.29	0.3	0.31	0.32	0.33	0.37	0.42	0.43	0.44	0.45	0.46	0.46	0.47	0.55	0.58	0.6	0.67	0.72	0.72	0.75	0.78	0.8	0.85	0.88	0.89	0.91	0.92	0.93	0.98	0.98	1		0.99	0.98	0.97	0.95	0.95	0.93	0.92	0.92	0.91	0.9	0.84	0.81	0.81	0.8	0.76	0.75	0.7	0.6	0.57	0.53
47	Item 9	0.02	0.13	0.15	0.15	0.17	0.19	0.2	0.22	0.22	0.26	0.27	0.28	0.28	0.28	0.29	0.29	0.3	0.31	0.32	0.36	0.41	0.42	0.43	0.44	0.45	0.45	0.46	0.54	0.57	0.59	0.66	0.7	0.71	0.73	0.76	0.79	0.84	0.86	0.88	0.9	0.91	0.91	0.97	0.97	0.98	0.99		0.99	0.99	0.96	0.96	0.95	0.94	0.93	0.93	0.92	0.86	0.83	0.83	0.82	0.78	0.76	0.72	0.61	0.58	0.54
48	Item 65	0.02	0.13	0.14	0.15	0.17	0.18	0.2	0.21	0.22	0.26	0.27	0.28	0.28	0.28	0.28	0.29	0.3	0.3	0.32	0.35	0.41	0.41	0.43	0.44	0.44	0.45	0.46	0.53	0.56	0.58	0.65	0.7	0.7	0.73	0.76	0.78	0.83	0.86	0.87	0.89	0.9	0.91	0.96	0.96	0.97	0.98	0.99		0.99	0.97	0.97	0.95	0.94	0.94	0.93	0.92	0.86	0.83	0.83	0.83	0.78	0.77	0.72	0.62	0.59	0.55
49	Item 37	0.02	0.13	0.14	0.15	0.16	0.18	0.2	0.21	0.22	0.26	0.27	0.27	0.27	0.27	0.28	0.28	0.3	0.3	0.31	0.35	0.4	0.41	0.42	0.43	0.44	0.44	0.45	0.52	0.55	0.57	0.65	0.69	0.69	0.72	0.75	0.77	0.82	0.85	0.86	0.89	0.89	0.9	0.95	0.96	0.97	0.97	0.99	0.99		0.98	0.98	0.96	0.95	0.95	0.94	0.93	0.87	0.84	0.84	0.83	0.79	0.78	0.73	0.62	0.59	0.56
50	Item 33	0.02	0.12	0.14	0.14	0.16	0.17	0.19	0.2	0.21	0.25	0.26	0.26	0.26	0.26	0.27	0.27	0.28	0.29	0.3	0.33	0.39	0.39	0.41	0.42	0.42	0.43	0.44	0.51	0.54	0.56	0.63	0.67	0.67	0.7	0.73	0.75	0.8	0.83	0.84	0.86	0.87	0.88	0.93	0.93	0.95	0.95	0.96	0.97	0.98		1	0.98	0.97	0.97	0.96	0.95	0.89	0.86	0.86	0.85	0.81	0.8	0.75	0.64	0.61	0.57
51	Item 47	0.02	0.12	0.13	0.14	0.15	0.17	0.19	0.2	0.21	0.24	0.25	0.26	0.26	0.26	0.26	0.27	0.28	0.29	0.3	0.33	0.39	0.39	0.41	0.41	0.42	0.42	0.44	0.51	0.53	0.55	0.63	0.67	0.67	0.7	0.73	0.75	0.8	0.83	0.84	0.86	0.87	0.88	0.93	0.93	0.94	0.95	0.96	0.97	0.98	1		0.98	0.97	0.97	0.96	0.96	0.89	0.86	0.86	0.86	0.81	0.8	0.75	0.64	0.61	0.58
52	Item 38	0.02	0.12	0.13	0.14	0.15	0.16	0.18	0.19	0.2	0.24	0.25	0.25	0.25	0.25	0.26	0.26	0.27	0.28	0.29	0.32	0.37	0.38	0.39	0.4	0.41	0.41	0.42	0.49	0.52	0.54	0.61	0.65	0.66	0.68	0.71	0.73	0.78	0.81	0.83	0.85	0.85	0.86	0.91	0.92	0.93	0.93	0.95	0.95	0.96	0.98	0.98		0.99	0.99	0.98	0.97	0.91	0.88	0.88	0.87	0.83	0.81	0.77	0.66	0.63	0.59
53	Item 14	0.02	0.11	0.13	0.13	0.15	0.16	0.18	0.19	0.19	0.23	0.24	0.25	0.25	0.25	0.25	0.25	0.27	0.27	0.29	0.32	0.37	0.37	0.39	0.4	0.4	0.41	0.42	0.49	0.51	0.53	0.6	0.64	0.65	0.67	0.7	0.73	0.78	0.8	0.82	0.84	0.84	0.85	0.9	0.91	0.92	0.92	0.94	0.94	0.95	0.97	0.97	0.99		1	0.99	0.98	0.92	0.89	0.89	0.88	0.84	0.82	0.78	0.67	0.64	0.6
54	Item 29	0.02	0.11	0.13	0.13	0.14	0.16	0.17	0.19	0.19	0.23	0.24	0.24	0.24	0.24	0.25	0.25	0.27	0.27	0.28	0.31	0.36	0.37	0.39	0.39	0.4	0.4	0.41	0.48	0.51	0.53	0.6	0.64	0.64	0.67	0.7	0.72	0.77	0.8	0.81	0.83	0.84	0.85	0.9	0.9	0.91	0.92	0.93	0.94	0.95	0.97	0.97	0.99	1		1	0.99	0.92	0.89	0.89	0.89	0.84	0.83	0.78	0.67	0.64	0.6
55	Item 23	0.01	0.11	0.12	0.13	0.14	0.16	0.17	0.19	0.19	0.23	0.24	0.24	0.24	0.24	0.25	0.25	0.26	0.27	0.28	0.31	0.36	0.37	0.38	0.39	0.39	0.4	0.41	0.48	0.51	0.52	0.6	0.64	0.64	0.67	0.7	0.72	0.77	0.79	0.81	0.83	0.83	0.84	0.89	0.9	0.91	0.91	0.93	0.93	0.94	0.96	0.96	0.98	0.99	1		0.99	0.93	0.9	0.9	0.89	0.85	0.83	0.79	0.68	0.64	0.61
56	Item 13	0.01	0.11	0.12	0.13	0.14	0.15	0.17	0.18	0.19	0.22	0.23	0.24	0.24	0.24	0.24	0.24	0.26	0.26	0.27	0.31	0.36	0.36	0.38	0.38	0.39	0.39	0.4	0.47	0.5	0.52	0.59	0.63	0.63	0.66	0.69	0.71	0.76	0.78	0.8	0.82	0.83	0.83	0.89	0.89	0.9	0.9	0.92	0.92	0.93	0.95	0.96	0.97	0.98	0.99	0.99		0.94	0.91	0.91	0.9	0.86	0.84	0.8	0.68	0.65	0.61
57	Item 64	0.01	0.09	0.1	0.11	0.12	0.13	0.15	0.16	0.16	0.2	0.2	0.21	0.21	0.21	0.21	0.22	0.23	0.23	0.24	0.27	0.32	0.32	0.34	0.34	0.35	0.35	0.36	0.42	0.45	0.47	0.54	0.57	0.58	0.6	0.63	0.65	0.7	0.73	0.74	0.76	0.77	0.77	0.83	0.83	0.84	0.84	0.86	0.86	0.87	0.89	0.89	0.91	0.92	0.92	0.93	0.94		0.97	0.97	0.96	0.92	0.9	0.86	0.74	0.71	0.67
58	Item 24	0.01	0.09	0.1	0.1	0.11	0.12	0.14	0.15	0.15	0.18	0.19	0.19	0.19	0.2	0.2	0.2	0.21	0.22	0.23	0.25	0.3	0.3	0.32	0.32	0.33	0.33	0.34	0.4	0.43	0.45	0.51	0.55	0.55	0.58	0.6	0.62	0.67	0.7	0.71	0.73	0.74	0.74	0.8	0.8	0.81	0.81	0.83	0.83	0.84	0.86	0.86	0.88	0.89	0.89	0.9	0.91	0.97		1	0.99	0.95	0.93	0.89	0.77	0.74	0.7
59	Item 8	0.01	0.08	0.1	0.1	0.11	0.12	0.14	0.15	0.15	0.18	0.19	0.19	0.19	0.19	0.2	0.2	0.21	0.21	0.23	0.25	0.3	0.3	0.32	0.32	0.33	0.33	0.34	0.4	0.43	0.44	0.51	0.55	0.55	0.57	0.6	0.62	0.67	0.7	0.71	0.73	0.73	0.74	0.79	0.8	0.81	0.81	0.83	0.83	0.84	0.86	0.86	0.88	0.89	0.89	0.9	0.91	0.97	1		0.99	0.95	0.93	0.89	0.77	0.74	0.7
60	Item 22	0.01	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15	0.18	0.19	0.19	0.19	0.19	0.19	0.2	0.21	0.21	0.22	0.25	0.29	0.3	0.31	0.32	0.32	0.33	0.34	0.4	0.42	0.44	0.5	0.54	0.54	0.57	0.6	0.62	0.66	0.69	0.7	0.72	0.73	0.73	0.79	0.79	0.8	0.8	0.82	0.83	0.83	0.85	0.86	0.87	0.88	0.89	0.89	0.9	0.96	0.99	0.99		0.96	0.94	0.89	0.78	0.75	0.71
61	Item 30	0.01	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.13	0.16	0.17	0.17	0.17	0.17	0.18	0.18	0.19	0.19	0.2	0.23	0.27	0.27	0.29	0.29	0.3	0.3	0.31	0.37	0.39	0.41	0.47	0.51	0.51	0.53	0.56	0.58	0.62	0.65	0.66	0.68	0.69	0.7	0.75	0.75	0.76	0.76	0.78	0.78	0.79	0.81	0.81	0.83	0.84	0.84	0.85	0.86	0.92	0.95	0.95	0.96		0.98	0.94	0.82	0.79	0.75
62	Item 42	0.01	0.07	0.08	0.08	0.09	0.1	0.12	0.12	0.13	0.16	0.16	0.17	0.17	0.17	0.17	0.17	0.18	0.19	0.2	0.22	0.26	0.27	0.28	0.28	0.29	0.29	0.3	0.36	0.38	0.4	0.46	0.49	0.5	0.52	0.55	0.57	0.61	0.64	0.65	0.67	0.67	0.68	0.73	0.73	0.74	0.75	0.76	0.77	0.78	0.8	0.8	0.81	0.82	0.83	0.83	0.84	0.9	0.93	0.93	0.94	0.98		0.95	0.84	0.8	0.76
63	Item 21	0.01	0.06	0.07	0.07	0.08	0.09	0.1	0.11	0.11	0.14	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.17	0.18	0.2	0.24	0.24	0.25	0.26	0.26	0.27	0.27	0.33	0.35	0.36	0.42	0.46	0.46	0.48	0.51	0.53	0.57	0.59	0.61	0.62	0.63	0.64	0.69	0.69	0.7	0.7	0.72	0.72	0.73	0.75	0.75	0.77	0.78	0.78	0.79	0.8	0.86	0.89	0.89	0.89	0.94	0.95		0.88	0.85	0.81
64	Item 39	0	0.04	0.05	0.05	0.06	0.07	0.07	0.08	0.08	0.1	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.13	0.13	0.15	0.18	0.19	0.2	0.2	0.2	0.21	0.21	0.26	0.28	0.29	0.34	0.37	0.38	0.39	0.42	0.44	0.47	0.5	0.51	0.52	0.53	0.54	0.58	0.58	0.59	0.6	0.61	0.62	0.62	0.64	0.64	0.66	0.67	0.67	0.68	0.68	0.74	0.77	0.77	0.78	0.82	0.84	0.88		0.96	0.92
65	Item 10	0	0.04	0.05	0.05	0.05	0.06	0.07	0.07	0.08	0.1	0.1	0.1	0.1	0.1	0.1	0.11	0.11	0.12	0.12	0.14	0.17	0.17	0.18	0.19	0.19	0.19	0.2	0.24	0.26	0.27	0.32	0.35	0.35	0.37	0.39	0.41	0.45	0.47	0.48	0.5	0.5	0.51	0.55	0.55	0.56	0.57	0.58	0.59	0.59	0.61	0.61	0.63	0.64	0.64	0.64	0.65	0.71	0.74	0.74	0.75	0.79	0.8	0.85	0.96		0.96
66	Item 26	0	0.04	0.04	0.04	0.05	0.05	0.06	0.07	0.07	0.08	0.09	0.09	0.09	0.09	0.09	0.1	0.1	0.1	0.11	0.13	0.15	0.16	0.16	0.17	0.17	0.17	0.18	0.22	0.24	0.25	0.3	0.32	0.33	0.34	0.36	0.38	0.42	0.44	0.45	0.46	0.47	0.47	0.52	0.52	0.53	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.6	0.6	0.61	0.61	0.67	0.7	0.7	0.71	0.75	0.76	0.81	0.92	0.96	

Appendix H

Validation questionnaire

Physical Asset Information Decision Making Framework for the South African Navy

Christian Fourie
August 2019

Validation Questionnaire

Introduction

Purpose of the questionnaire
Validation of Master of Engineering (Industrial) thesis

Purpose of the study

The study is in the field of Physical Asset Management. The research aims to construct a decision making framework for understanding the effect of asset information (AI) on the core outputs of the SAN. The availability of assets is a measureable concept that could be linked to the core outputs of the SAN. The outputs being: 1) Conducting ordered defence commitments in accordance with government policy and strategy (measured by the number of hours at sea per year), and 2) providing mission ready defence capabilities (measured by the percentage compliance with joint force employment requirements). Both outputs can be related directly to achieving the desired Operational Availability (A_O).

The intention of the study is to uncover the role of specific AI elements in achieving A_O and form an AI decision making framework. The foreseen value of the decision making framework is that it could aid in prioritisation and AI related decision making by providing perspective and insight as to the worth of various AI elements. The criteria against which each AI element is measured emanate from the ISO 55000 standard. This standard describes informed asset decisions and the realisation of value being based on the balance of cost, risk and benefit. The decision making framework provides the means to quantify the preferences of a decision maker towards each of the conflicting criteria. It also provides the ability to compare the normally incomparable attributes of AI elements as per the three criteria.

Important considerations and information

- Personal information is confidential. Any information you share with me in this questionnaire that could possibly identify you as a participant will be protected. This will be done by allocating a unique code to you that is only available to the researcher. You will remain anonymous to other participants throughout the study and only the researcher will be able to identify your specific answers. The information collected will only be used for this study. The results of the study will be published as part the primary researcher's Master of Engineering thesis.

- You can choose whether to be in this study or not. If you agree to take part in this study, you may withdraw at any time without any consequence and may choose to have the information you provided removed. You may also refuse to answer any questions you don't want to answer and still remain in the study. The researcher may withdraw you from this study if circumstances arise which warrant doing so.

- Approval for the study has been granted by the Department of Defence Chief Director Counter Intelligence. If you however feel that any information you provide are of sensitive nature you can contact the researcher and measures can be put in place to protect the information.

- The supervisor for this study is:

  Dr J.L. Jooste (wyhan@sun.ac.za; 021 808 4234).

- The primary researcher is:

  Christian Fourie (christian.fourie@gmail.com; 061 515 2625).

Study background, context and research problem

Making productive asset related decisions requires organisations to equip their personnel with the correct information at the right time, and in the right format. In-service feedback data can be collected from systems operating in their intended operating environments during the operational deployment and maintenance phase of assets. During this phase, the System Engineering function typically analyse performance, monitor interfaces, conduct failure analysis, analyse logistics, and track and manage that which are essential to the ongoing support of the system. Various elements interact during this phase to enable the asset to fulfil its mission. One of these elements is AI which, in typical systems thinking, influences all other elements in the system and has its own elements. Collecting and managing information which is required for informed decision making costs money. The ultimate achievement is to collect and maintain all data elements as described in Physical Asset Management literature, but many organisations find it challenging and not cost effective. Some areas will either not yield the same return as what was invested or have negligible effects, whilst areas that could potentially have advantageous results are neglected.

The problem is that there is no framework available to aid decision making regarding asset information in the SAN. From the problem statement flows the primary research question, which is: Can an Asset Information Decision Making Framework be constructed for the SAN?

The secondary research questions are: What critical decisions, which require AI as input and affects operational availability of systems in the SAN, are taken? What are the AI data streams that support the critical decision making affecting operational availability in the SAN? How can a framework be constructed to understand the impact of each of the AI components on operational availability?

In order to answer the research questions an exploratory sequential mixed method design is adopted. This design sees qualitative data collected and analysed, before commencing with the second phase, which is quantitatively orientated. The first and second research questions are open ended questions that require exploration in the field. This is addressed in the first phase, which starts with a questionnaire ascertaining which decisions are made by Products System Managers in the SAN, using AI. These decisions need to impact on the A_O of military systems as the main aim is to quantify the impact of AI on core outputs via it.

By first identifying significant AI based decisions, the research approach is making use of a pull strategy to identify frequent data and AI needs. This top-down approach of first establishing the needs also validates the AI elements identified for use in phase two of the study.

To answer the third research question a quantitative approach is used. The data collected in the first phase are used together with a hybrid Analytic Hierarchy Process - Multi Attribute Utility Theory algorithm to construct questionnaire. This questionnaire makes use of closed ended survey questions. During the second phase the relative weight of importance, or ranking, in terms achieving the desired A_O is assigned to the AI elements identified in the first phase. This information is at the crux of the South African Navy's Asset Information Decision Making Framework (SANAIDMF). The SANAIDMF is ultimately validated by face validation and user assessment.

The research boundaries are:

1. The study did not attempt to investigate the AI base for all decisions made in the SAN, but focused only on decisions deemed critical to A_O by experts in the field.

2. The research is furthermore limited to AI required for decisions making in the operational deployment and maintenance life cycle stage. The effects of what was implemented in the previous life cycle stages are observed in the operational deployment and maintenance stage, providing empirical evidence. Grounding the SANAIDMF in the operational deployment and maintenance life cycle stage reduces variables and creates more confidence in the validity of the framework. The information needs as per the SANAIDMF is however of interest to other life cycle stages and can be incorporated accordingly.

3. In this study a framework is defined as a network of concepts that together provides a comprehensive understanding of a phenomenon, not an explanation. A theoretical framework provides insight that makes sense in real world. The SANAIDMF is not intended to be a prescriptive model that describes statistical significance between variables, but rather a framework that provides an understanding of AI phenomena. It aids the decision making process, but does not make decisions on behalf of the decision maker.

The SANAIDMF is presented on the next page. It is important to note that the SANAIDMF produced by this study is intended as a baseline iteration of a dynamic framework that should be tailored for products systems as critical decision and information requirements change or more accurate input information becomes available. The Microsoft Excel format of the SANAIDMF is provided with this questionnaire to experiment with the active use of the framework.

	Asset Information element	Attributes (Scale 1 to 10)			Calc scores - inverse Cost & Risk			Utility Score	Rank - descending order of preference
		Value to Ao	Cost of Information	Risk	Value to Ao	Cost of Information	Risk		
Item 4	Budget information	7,667	1,000	3,000	7,667	10,000	8,000	8,183	1
Item 18	Human resource strategies and plans to replace maintenance personnel with suitably qualified stand in personnel	8,333	1,667	6,667	8,333	9,333	4,333	7,230	2
Item 17	Human resource personnel shortage prevention measure strategies	7,333	1,667	5,333	7,333	9,333	5,667	7,170	3
Item 6	Consumable products allowance lists	6,333	2,333	3,667	6,333	8,667	7,333	7,140	4
Item 5	Capacity of repair sections to conduct outstanding maintenance	7,000	2,333	4,667	7,000	8,667	6,333	7,087	5
Item 66	Work to be performed during maintenance or alterations to equipment	8,333	3,667	5,333	8,333	7,333	5,667	7,030	6
Item 46	Projected missions	7,000	4,333	3,667	7,000	6,667	7,333	6,970	7
Item 59	Supply lead times	8,333	5,333	4,333	8,333	5,667	6,667	6,927	8
Item 61	Turnover amount of stock	7,333	5,333	3,000	7,333	5,667	8,000	6,910	9
Item 49	Required delivery schedule	7,333	4,333	4,667	7,333	6,667	6,333	6,793	10
Item 12	Equipment sensitivity towards number of uninstall and install procedures	5,333	4,667	1,333	5,333	6,333	9,667	6,767	11
Item 63	Upcoming maintenance requirements	8,333	4,000	6,000	8,333	7,000	5,000	6,753	12
Item 16	Historical cost data	4,667	3,000	2,000	4,667	8,000	9,000	6,753	13
Item 45	Projected equipment priorities	7,000	5,333	3,667	7,000	5,667	7,333	6,750	14
Item 11	Equipment required to perform maintenance and alteration work on equipment	7,333	4,000	4,333	7,333	7,000	6,667	6,740	15
Item 52	Status of training material and training aids	7,333	5,000	4,000	7,333	6,000	7,000	6,730	16
Item 3	Allowances of original design parameters such as weight increase, load increase, usage increase as well as structural strength and integrity.	6,000	3,667	2,667	6,000	7,333	8,333	6,693	17
Item 32	Number of candidates for refurbishment	5,000	3,667	2,333	5,000	7,333	8,667	6,687	18
Item 19	Industry support contract information	5,000	4,000	1,333	5,000	7,000	9,667	6,650	19
Item 48	Readiness level required	6,333	5,667	2,333	6,333	5,333	8,667	6,573	20
Item 41	Period by which the maintenance downtime will be extended to catch up on maintenance once the product system is no longer operationally required	9,000	2,000	8,000	9,000	9,000	3,000	6,460	21
Item 54	Stock usage history	7,000	7,333	4,667	7,000	3,667	6,333	6,447	22
Item 62	Unplanned breakdown information	6,667	4,667	4,667	6,667	6,333	6,333	6,417	23
Item 51	Status of training facilities	7,000	5,000	4,333	7,000	6,000	6,667	6,400	24
Item 35	Number of mission related products to be procured	7,667	5,333	5,333	7,667	5,667	5,667	6,390	25
Item 58	Supplier production planning	5,667	6,000	2,000	5,667	5,000	9,000	6,380	26
Item 44	Product lead time	6,000	5,000	3,000	6,000	6,000	8,000	6,360	27
Item 15	Handover procedures (record keeping)	5,333	3,667	3,667	5,333	7,333	7,333	6,230	28
Item 27	Maintenance history	7,000	6,667	3,667	7,000	4,333	7,333	6,180	29
Item 31	Modification instructions	4,333	5,333	2,000	4,333	5,667	9,000	6,147	30
Item 43	Previous refurbishment details	5,000	6,000	2,333	5,000	5,000	8,667	6,027	31
Item 20	Information on alternatives available in the market	5,667	5,333	4,000	5,667	5,667	7,000	5,963	32
Item 57	Supplier data	8,333	5,000	7,333	8,333	6,000	3,667	5,957	33
Item 36	Number of products likely to require modifications	5,000	5,667	3,000	5,000	5,333	8,000	5,917	34
Item 40	Original product system acquisition plan	6,000	5,667	3,333	6,000	5,333	7,667	5,870	35
Item 2	Accurate job-card feedback	8,000	6,000	6,000	8,000	5,000	5,000	5,837	36
Item 60	Target inventory levels	8,000	7,333	5,667	8,000	3,667	5,333	5,763	37
Item 1	Accurate costing of spares and materials	6,667	5,000	5,667	6,667	6,000	5,333	5,723	38

	Asset Information element	Attributes (Scale 1 to 10)			Calc scores - inverse Cost & Risk			Utility Score	Rank - descending order of preference
		Value to Ao	Cost of Information	Risk	Value to Ao	Cost of Information	Risk		
Item 34	Number of each type of spares to be used in maintenance and other support activities	8,000	6,000	6,667	8,000	5,000	4,333	5,703	39
Item 25	Inventory re-order points	8,333	5,667	7,333	8,333	5,333	3,667	5,673	40
Item 50	Spares required for preventive and corrective maintenance as well as alterations on equipment	9,333	6,333	8,333	9,333	4,667	2,667	5,663	41
Item 28	Maintenance task information	7,667	7,333	5,667	7,667	3,667	5,333	5,653	42
Item 55	Studies detailing the overall effect on operational availability if some sub systems are being used more than originally planned	6,000	7,000	4,000	6,000	4,000	7,000	5,577	43
Item 56	Studies on the long term effect of delaying maintenance on the product system	5,667	7,333	3,333	5,667	3,667	7,667	5,573	44
Item 7	Accurate costing of services required	7,333	6,333	5,333	7,333	4,667	5,667	5,557	45
Item 53	Strategies to reduce readiness and usage levels to ease the utilization of equipment	5,667	4,667	3,000	5,667	6,333	8,000	5,550	46
Item 9	Design change impact studies	4,667	5,667	3,000	4,667	5,333	8,000	5,530	47
Item 65	What if scenario's and strategies related to reducing the number of available systems, maintenance of sub-systems, changing maintenance philosophy and changing training policies	6,333	8,000	3,667	6,333	3,000	7,333	5,520	48
Item 37	Number of products requiring scheduled maintenance	8,667	6,000	8,000	8,667	5,000	3,000	5,510	49
Item 33	Number of each type of mission related products to be re-supplied	7,000	5,667	6,667	7,000	5,333	4,333	5,480	50
Item 47	Qualified OSBL	7,667	6,667	7,000	7,667	4,333	4,000	5,477	51
Item 38	Number of systems required to be online in a given period	7,333	7,333	5,333	7,333	3,667	5,667	5,453	52
Item 14	Failure rate data	7,333	7,667	5,333	7,333	3,333	5,667	5,440	53
Item 29	Materiel and usage accounting	6,333	6,333	5,000	6,333	4,667	6,000	5,433	54
Item 23	Information on what proportion of repairs are likely to take place at each level of maintenance	7,000	7,667	5,000	7,000	3,333	6,000	5,427	55
Item 13	Expiration dates of stock in depot	5,667	4,000	6,667	5,667	7,000	4,333	5,413	56
Item 64	Usage history	6,667	7,667	4,667	6,667	3,333	6,333	5,327	57
Item 24	Inventory levels	7,667	6,333	6,667	7,667	4,667	4,333	5,283	58
Item 8	Data showing the difference between predicted hours and material vs actual hours and material used per standard maintenance task	6,333	6,000	5,333	6,333	5,000	5,667	5,280	59
Item 22	Information on the availability of skills and special tools at the relevant maintenance level	7,000	6,000	6,333	7,000	5,000	4,667	5,270	60
Item 30	Minimum stock levels	6,667	7,000	5,667	6,667	4,000	5,333	5,210	61
Item 42	Predicted stock usage for planned activities	8,333	6,667	8,000	8,333	4,333	3,000	5,187	62
Item 21	Information on systems being operated in other military environments	3,333	6,000	3,333	3,333	5,000	7,667	5,120	63
Item 39	OEM Last time buy and technical support information	7,000	8,333	5,667	7,000	2,667	5,333	4,953	64
Item 10	Divisions between mission critical spares and all planned spares	5,000	6,000	5,333	5,000	5,000	5,667	4,903	65
Item 26	LSA data	7,000	8,667	6,000	7,000	2,333	5,000	4,843	66

Questions

Considering the above, and the Excel format, please answer the following questions.

1. In your opinion, what is the potential of the SANAIDMF to prove useful in aiding decision making in the South African Navy (SAN)?

   Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good ☐

   Additional comments:

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2. In your opinion, what are the strengths of the SANAIDMF as well as the research objectives and methodology that was followed?

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3. In your opinion, what are the weaknesses of the SANAIDMF and the methodology that was followed?

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4. Please rate the following aspects of the SANAIDMF:

   a. Ease of understanding?

      Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good ☐

   b. User friendliness and ease of use?

      Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good ☐

c. Perceived practicality in real world application?

Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good ☐

d. Flexibility, and the ability to adapt the framework to new information or requirements?

Very poor ☐ Poor ☐ Fair ☐ Good ☐ Very good ☐

5. What improvements can be made to the SANAIDMF in your opinion?

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6. Would you utilize the SANAIDMF if you were in a position to improve Asset Information integrity in the SAN? If not, please substantiate why not?

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7. Do you have any additional comments?

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Participant information

Please supply the following information

Job title: ____

Primary responsibilities: ____

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Professional background and experience: ____

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